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Dorcas G. Beer

Penna Fem College '88

GEOLOGICAL STUDIES;

OR,

ELEMENTS OF GEOLOGY.

FOR

HIGH SCHOOLS, COLLEGES, NORMAL, AND OTHER SCHOOLS.

PART I.—GEOLOGY INDUCTIVELY PRESENTED.
PART II.—GEOLOGY TREATED SYSTEMATICALLY.

WITH 367 ILLUSTRATIONS IN THE TEXT.

BY ALEXANDER WINCHELL, LL.D.

PROFESSOR OF GEOLOGY AND PALÆONTOLOGY IN THE UNIVERSITY OF MICHIGAN, FORMERLY DIRECTOR OF THE GEOLOGICAL SURVEY OF MICHIGAN, AUTHOR OF "GEOLOGICAL EXCURSIONS," FOR ELEMENTARY SCHOOLS, ALSO OF "SKETCHES OF CREATION," "WORLD LIFE," ETC., ETC.

SECOND EDITION

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CHICAGO

"THE diffusion of that which is specially named science has at the same time spread abroad the only spirit in which any kind of knowledge can be prosecuted to a result of lasting intellectual value."—PROFESSOR JEBB.

"All the subjects which the sixteenth century decided were 'liberal' are studies in books: but natural science is to be studied not in books, but in things."—PRESIDENT ELIOT.

"The genesis of knowledge in the individual must follow the same course as the genesis of knowledge in the race."

"Every study should have a purely experimental introduction."—HERBERT SPENCER.

"Were I dictator, I would drive all teachers of science out into the great field of dead work; force them to go through all the gymnastics of original research and its description, and not permit them to return to their libraries until their note books were full of their own measurements and calculations, sketch maps, and farm drawings, severely accurate, and logically classified, to be then compared with those recorded in the books."—JOSEPH P. LESLEY.

PREFACE.

THIS work on the elements of geology is intended as a guide in the observation of nature, and a synoptical record of the more important facts and doctrines of the science. The reader is supposed to be desirous of laying substantial foundations for a geological education, and to have attained such mental development as to require a text book more advanced than the Author's "Geological Excursions." The method, as in that work, is an appeal to the powers of observation; and the facts cited are the most familiar and most accessible. Happily, the widespread Drift of the northern portion of the continent brings to nearly every student's door a body of phenomena so similar as to supply an intelligible common starting point for a very large proportion of the United States and Canada; while for students of the southern states, any inconveniences may be easily overcome. Though this method is believed to be unique, it is, without question, the method which best comports with the order of development of the mental faculties, and must prove most easy and gratifying to the student. It is the application to geology of those sound principles which have come into vogue among the best modern teachers of the other sciences of nature. That it is entirely practicable is shown by the personal experience of the Author, and of many other teachers who have used the more rudimental work above mentioned.

What there is among the universal phenomena of the Drift to serve as the elementary data of geological science will perhaps be best understood by turning over the earlier pages of the First Part of the book. The Author does not, however, imagine the pupil a mere recording instrument; but bears in mind the fact that the dawn of reflection is simultaneous with the exercise of perception. The observer begins immediately to grou nomena — to generalize, and to inquire after those antecedents which science denominates causes. The encourages this tendency by pausing occasionally to re summarize, to induce a general principle, and even to th little. Thus, in the First Part, scientific method is un The science is growing up in the learner's mind simulta and symmetrically in all its departments, just as it grev intelligence of mankind.

A little later, after the nearest phenomena have yield lessons, the learner is led from home to widen his obser Well, indeed, if the travel can be real, like the earlier ex into the neighborhood. But the impracticability of th rule, is offset, as far as possible, by graphical illustrati many cases, it may be further offset by specimens, mod diagrams. These the school, or the teacher, or even t himself, may, to some extent, provide. As, after a things can only be known from descriptions, the effort made to have them intelligible.

The purpose to begin with the Drift has led to a mo study of common minerals and rocks than has hereto undertaken in elementary works; but this feature, t believes, requires no defence. On the contrary, he assured that the tables provided for determinations and rocks from their most obvious characters will rece welcome; and will satisfy many longings to kno more about the objects which are absolutely the and familiar which we encounter.

The same purpose has led to a more particular common types of fossils than has ordinarily been t priate. But this study has been restricted mainl widely distributed in the Drift, and therefore ge ble; and it has been pursued only far enough to i study fossils in a scientific way.

The outcome of the First Part is a somew undigested mass of facts and doctrines, buried volume of verbiage. It does not, assuredly, supply the means for a methodized apprehension of the elements of the subject. But it supplies many fundamental facts, many great principles, many impressions, many hints for personal observation, and many impulses to continue. Far better for the student to get so much than to leave school in total ignorance of a science which sustains so important relations to industries, to culture, and to civilization.

Part II is the complement of this. Here the whole body of facts and principles is reduced to methodical re-presentation; though the necessity of abridgment has led, in some of the chapters, to mere references to the First Part, instead of recastings of the matter. Here, too, the discussions of the several topics are completed, and the various portions are adjusted to a logical relation. The last chapter is a rapid historical sweep over the whole range of terrestrial events. To a limited extent, therefore, the book may be used for elementary reference. But it must not by any means be conceived as intended for a manual. The method of a manual is suited only for advanced students and investigators. A very different method is demanded by beginners. This is only to a limited extent even a "text book." That term savors of an educational method which is obsolete and repugnant. The present work is a guide to the study of nature, and a synopsis of the elementary facts and principles of geological science.

Because the work is elementary, it has been restricted almost wholly to American geology. But no well beaten path has been pursued. The recent additions to our knowledge of American geology have greatly transformed the science, and the subject has to be treated very much as if no elementary books had been written. Recent investigations have placed us in possession of a large body of information about the remote interior and the Pacific slope, and the vast region north of our national boundary. To this fresh information the author has attempted to give due attention. It will be found a feature of the work, that it surpasses other elementary books in its presentation of western

geology, especially in its great features and its gre
facts.

The author's obligations, of course, lie in ever
they are, indeed, too many to enumerate. But th
been made to draw less on the writers of text bo
original sources. To his publishers, his indebtedness
the public is great, for that intelligent liberality
prompted them to demand, regardless of cost, the b
graphic illustration, and a perfection of mechanica
which will scarcely be found surpassed.

The author entertains the hope that he has h
within reach of his fellow-workers in the advanceme
lar education some improved means for placing geolo
where of right it belongs — side by side with the mo
and most favored agencies of material prosperity, of
and of culture.

UNIVERSITY OF MICHIGAN, Ann Arbor, June, 1886.

PREFACE TO A NEW EDITIO

THE exhaustion of the first edition of this work
months of its introduction into use is sufficient
its acceptability as an elementary guide to the science
Among the numerous opinions which have reached
respecting its method and matter, no one is seriou
while commendations are almost unlimited in numbe
author begs to request teachers in schools where the
to geology is quite brief, to remember that the bulk
results partly from the method of treatment; and tha
chosen for the purpose of rendering the subject enter
building up a knowledge of it in a natural way.
course, Part I. may be taken by itself; and then Part
taken later. Also, the studies of fossil corals and sh
I. may be postponed, as well as the palæontological
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palæontology.

FEBRUARY, 1887.

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SUGGESTIONS TO THE INSTRUCTOR.

1. Adhere scrupulously to the *method* of the book. Vary the facts, illustrations, comments, and inferences according to opportunity or ability.

2. Do not permit any persons to thrust upon your attention, or that of the pupils, any specimens not yet considered in the book. Most persons have a few treasured minerals from some remote mining region upon which you will be asked to pronounce opinions. Do not be annoyed by them. The specimens at your door are incalculably more important.

3. Give deliberate attention to the exercises. See that every pupil learns to elucidate every subject presented in them. Occasionally a question is raised which even the teacher may not be prepared to solve. That is intended. It is profitable to have something to study over.

4. If the class is small — say, not over a dozen — they may be ordinarily taken into the field. This is always the *best* course. If the class is large, the subject may be pursued chiefly in the class-room; but illustrations should be abundant. In the study of minerals and rocks, a large supply of specimens, *all broken from the same bowlder*, may be furnished, and one specimen placed in the hands of each student. The teacher will then direct attention to every character visible in the specimen, pursuing the same method as the teacher of botany. The rock must have been previously selected with reference to showing what is treated in the study appointed for the day.

When this specimen is well understood, another set may be distributed, and so on.

5. After a few exercises of this kind, individual students may be required to name such minerals in the specimen in hand as have been previously studied. Then, after the work is more advanced, a mixed lot of specimens may be brought in, and individual students requested to determine them. Reports should be made on slips of paper, and returned with the specimen. These may be examined immediately, if time permits, or after the exercise. The student's report should state all the facts on which the name of the specimen depends: Stratified or not; thick- or thin-bedded; what essential minerals; what accessory minerals; the name. These exercises should be continued for many days after the end of the subject of rocks is reached in the book.

6. Get supplies of rock specimens, if the class is large, by having two students volunteer to bring a basket full on the following day, and two others to bring another basket full, and so on. The specimens should be preserved in drawers for future use, both during the present and subsequent terms. If the class is small, a supply should be in store for use when the weather may prevent field work.

7. Generally, fragments of bowlders broken for building purposes may be found, and further reduced with the small hammers. If not, the collector must use a large hammer for breaking bowlders. This should belong to the school. If necessary, a workman may be taken along. In some cases it will be most convenient to have a large supply of bowlders brought into one corner of the yard, or deposited under a shed. These may all be coarsely broken at once by a workman. Smaller fragments may be produced by the students as needed; but specimens from the same bowlder should be kept together. This method may be best suited to some girls' schools, to institutions in large cities and in other localities where Drift specimens are not easily accessible.

In a region destitute of bowlders a supply may be obtained from some bowlder-covered region, by causing to be shipped as freight a number of bowlders of different sorts of rocks, either unbroken and unboxed or broken into hand specimens and boxed. The author has already sent boxed specimens to the southern states and to the Illinois prairies.

9. Encourage the procurement of a good supply of hammers and lenses by the students. They may be regarded as essential to satisfactory work. The lenses are almost indispensable in the examination of rocks.

10. Encourage the formation of private collections, and see that they are kept properly ticketed. See that a good collection is formed for the school. Procure, if possible, from some dealer a standard collection of common minerals and rocks.

11. Embrace every opportunity to require drawings. Blackboard drawings are useful; but careful sketches on drawing paper are better. Sketches of cliffs, quarries, gravel banks, ravines, fossils, or any other geological features or phenomena should be required of all.

12. Dwell long on the subject of *geological sections*. Nothing is a more useful exercise for the pupil than the construction of sections from the geological map. If the locality permits, have the students also construct sections, with measurements, from the field.

13. Require each student to construct a tinted geological map. Preferably a map of the United States east of the Black Hills, or better, of the whole country. The maps in the text book may be enlarged; or, for more accuracy, the map of the U. S. Geological Survey may be used.

14. Require every student to make, also, collections of fossils, and to

determine their names if possible. Do not fail to secure exercises in grinding, polishing, and investigating, as indicated in Study XXX of this book.

15. The production of a neat and accurate geological map may well abate considerably the rigor of a final examination. The same may be said of a well labelled collection of specimens, or a number of well prepared thin sections, or a larger number of polished surfaces of rocks or fossils. In this first stage of the study, the senses and the hands are to be kept in full exercise. These will supply motives for the pleased activity of imagination, memory, and the reasoning powers.

SOME PRACTICAL HINTS.

Hammers.—The best forms of Hammers for general use are shown in Figs. 1 and 2. The palæontologist's pattern, with pene *a* tapering and sharp, and transverse to the handle, is by far most convenient in collecting fossils. The face *b* should be flat, square cornered, and longest in the direction of the handle. The eye should be large; the handle of hickory, thick, short, and shaped as shown, and fastened in with two iron wedges. Weight may be from half a pound to a pound. For working among very hard rocks, the stonemason's pattern is better. The pene is parallel to the handle, less tapering, and blunter. The temper of all hammers should be that required by the stonemason. Notice, the pene of the palæontologist's hammer must not be used on quartzose rocks.

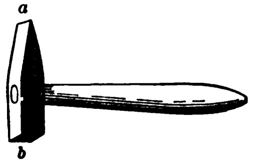


FIG. 1.—GEOLOGICAL HAMMER. PALÆONTOLOGIST'S PATTERN.

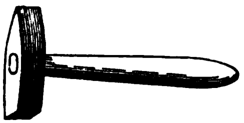


FIG. 2.—GEOLOGICAL HAMMER. QUARRYMAN'S, OR STONEMASON'S, PATTERN.

Larger quarryman's hammers, with long handles for use with both hands, and weighing from two to five pounds, are needed for breaking large bowlders; but one at the service of the class is sufficient.

Using the Hammer.—A blow with the flat face of the hammer in the middle of a fragment shatters it irregularly. A blow with the face a little inclined, or with the pene of the hammer, tends to produce a fracture in the direction of the face-edge, or the pene. If the object is to reduce the size of a specimen, or dress it into form, a quick, sharp blow with the face-edge or the pene, delivered near the margin of the specimen, will cause a break only along the line of contact. If the edge is too thick to break in this way, make it thinner by clipping off with blows along the edge near the angles.

A steel-faced anvil, weighing ten to twenty pounds, is useful in dressing specimens, and in breaking up masses for the removal of fossils. For the former object, hold the specimen so that the portion to be removed projects beyond the anvil face, and the specimen rests solidly on the edge of the face. Then strike a sharp blow on the projecting part, and it will break off along the line of contact with the anvil.

To break a large bowlder, strike repeatedly with the pene of a heavy quarryman's hammer along a selected line. Sooner or later the bowlder will split.

Hardness Tester.—A steel rod, wedge-shaped and pointed at one end, as shown in Fig. 3, is convenient; but an old three-cornered file ground to a point is just as efficient. In default of both, a well tempered knife point may be used. Whatever tester is adopted, use the same habitually.

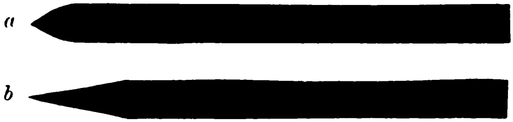


FIG. 3.—HARDNESS TESTER. *a*, View of the Flattened Side of Point. *b*, View of the Taper toward the Point.

Magnifiers.—A simple pocket magnifier is indispensable in the examination of minerals and rocks. A glass with a single lens will be suitable. A larger size than these figured is preferable. Get nothing but a *pocket* magnifier.

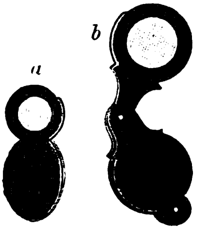


FIG. 4.—MAGNIFIERS. *a*, Oval. *b*, Bellows Shaped.

Acid.—A small glass-stoppered bottle of dilute chlorhydric (muriatic) acid should be at hand in the class room for testing carbonates. A drop may be taken out on the tip of a blunt stick, and applied to the specimen. In the lack of such acid very strong vinegar will answer in some cases; but do not depend on it.

Tickets.—Small tickets, to be permanently attached to specimens to receive numbers, may be circular, oval, or other shape, three-sixteenths of a inch (five millimetres) in diameter, punched from *thin* white or colore paper that will take ink. A common saddler's or tinner's punch may b used. Fold the paper, and punch through many thicknesses with one blov resting on a block of lead or wood. As the tickets will tend to adhere, lay a quantity in the palm of one hand, and rub them with the finger tips of the other. Square, oblong or triangular tickets may be cut with scissors.

Cement.—Do not use common mucilage. Take

Clear Gum Arabic	2 ozs.
Fine Starch	1½ oz.
White Sugar	½ oz.

Pulverize the gum arabic in a mortar, and dissolve in so much water as the laundress would use for the quantity of starch indicated. Dissolve the starch and sugar in the gum solution. Then cook the mixture in a vessel suspended laundry fashion, in boiling water, until the starch becomes clear. The cement must be as thick as tar, and must be kept so. Use from a wide-mouthed bottle, having a small round bristle-brush passing through the cork. Keep from spoiling by means of a lump of camphor gum, or a little oil of cloves or sassafras. Do not use cement that has grown sour and thin. Some of the fresh-made cement may be hard-dried in greased patty-pans, and then removed and kept indefinitely, to be softened when needed—a good expedient for a long journey. This cement may be used to repair minerals, rocks, or fossils, and to attach tickets. One lot of cement will serve several persons.

Attaching Tickets.—Spread a quantity of specimens on a table, with the side to be ticketed turned up. Spread, also, a quantity of tickets, so separated as to lie singly. With the point of the brush, touch half a dozen specimens in the proper place with the cement. With the moistened tip of the finger, lift a ticket, and press it on a gummed spot. Press firmly, till the ticket takes the shape of the surface, and the cement is forced quite to the edges. Then, as some cement adheres to the finger, rub the finger tip on a damp towel. This removes the cement, and leaves the finger damp to lift another ticket. Thus the process of attaching is expeditious.

The Numbers.—To write the numbers on the tickets, after well dried, use perfectly black ink, and a sharp, good, and fresh steel pen. Make your very plainest figures. These are a permanent record; illegible numbers are a vexation. The numbers refer to a register, where, against corresponding numbers, may be found columns giving name, locality, how obtained, and other information. Separate labels bearing the names and the same numbers may also be used.

Colored Tickets.—If each person in a class or company adopts a particular color for his tickets, then all the specimens of the company may be mixed, and may be classified as one lot; and afterward each person can select his own. See that the colored paper is *writing* paper, and color distinct and *fast.* Separate ownership may also be indicated by the form of the ticket.

Map Drawing.—To put the preliminary geography on the sheet is a valuable exercise, but is not a study of geology. The work may be done as an accessory in the study of geography, or an exercise in drawing. For our purpose procure blank (uncolored) printed maps if possible. These may sometimes be had of map publishers. Rand, McNally & Co., of Chicago, have for some years supplied the University of Michigan. They print a very large assortment of maps; but they do not keep in stock blank impressions such as we need; they have to be specially printed when called for, and the call should be for fifty or more. The writer uses a map of the entire United States; and the best suited is their so-called "standard map," twenty-six inches by forty-three and one-half inches, 1882; or the later one, thirty and one-half inches by forty inches, 1885. Either is a complete railroad map. When geologically colored and mounted, it makes a useful chart for reference, as well as a pleasing souvenir of faithful work.

Cloth Backing.—This is not essential but very serviceable. Dampen a piece of fine muslin of requisite size. Stretch it firmly on a smooth board by tacking it down. Paste the back of the map with smooth flour paste applied with a large, stiff, flat brush. Lay the pasted surface on the stretched cloth, carefully excluding all air by holding the edges of the map up and allowing the centre to come first in contact. Press the two surfaces together by rubbing from the centre toward the sides *through the medium of a cloth.* It is best to leave the whole attached to the board or table until the map is completed. Then the edges may be trimmed, and the map mounted on rollers.

Geological Colors.—As yet, no set of colors has been agreed upon for general use; but the following table indicates customary usage:

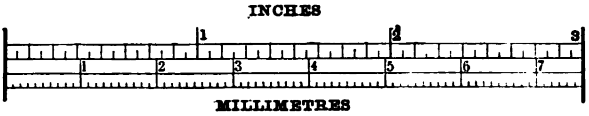
FORMATIONS.	COLORS.	MATERIALS.
Tertiary.	Yellow.	Gamboge.
Cretaceous.	Green.	Gamboge and Blue Ink.
Jura-Trias.	Purple.	Carmine and Blue Ink.
Upper Carboniferous.	Brown.	Burnt Umber.
Lower Carboniferous.	Blue.	Blue Ink.
Devonian.	Yellowish Brown.	Gamboge and Burnt Umber.
Silurian.	Red Purple.	Blue Ink and Much Carmine.
Cambrian.	Slate.	India Ink and Blue Ink.
Eozoic.	Orange Red.	Carmine Ink and Gamboge.
Eruptive.	Bright Red.	Carmine Ink.

The above is sufficiently detailed for the elementary student, and requ but a very simple outfit, one of which will supply several persons. W subdivisions of these formations are to be indicated, use lighter and de shades of the same colors — the lighter for the newer formations. For deeper yellow, orange may be used. Put on a blank space a legend explanatory of the colors.

These colors may be used on the map published in the text book. They may also be used on sections.

Avoid colors too deep. Avoid the use of too much paint. Make sharp, clean outlines. Be exact. Use large camel's hair brushes.

Wall Maps.—Get cotton sheeting of requisite width, and cut length in proportion to the width — calculating from the dimensions of the map to be enlarged. Use dry pulverized colors mixed in weak glue water. Stretch the cloth on a frame erected vertically in a room. It may be like a quilting frame, in four pieces, with holes and pegs for varying the size. Tack the cloth thoroughly. Prepare the ground with one or two coats of whiting and glue water. When dry, pencil in lines of latitude and longitude, at intervals calculated from the map to be copied; and from these pencil in the geography. In the same manner lay down the geological outlines. Then apply the colors, and lastly put in the lettering, rivers, boundaries and whatever else requires the black — which will be made of lampblack and glue water. You cannot put the colors over the lampblack. Do not omit the explanatory legend. Cut the top and bottom straight and mount on rollers. Caution: Use only glue enough to make the colors adhere.



GEOLOGICAL STUDIES.

PART I.

FIELD STUDIES;

OR, HOW WE MAY OBSERVE THE FACTS AND LEARN THEIR MEANING.

STUDY I.—*Surface Materials.*

I DESIRE by some natural and pleasant method to introduce my young friends to the science of geology. I trust the study of the subject will prove entertaining, but I shall endeavor at the same time to put them on a truly scientific course. The method which seems most suitable for us in the beginning is that called *inductive.* We propose to see things for ourselves, and draw our own conclusions from them. For the present we will confine our attention mostly to such things. But when our walks shall have extended over the fields most accessible to us, we will enlarge our information by talks on other fields in which other persons have walked.

As *geology is the science which treats of the earth,* we have not far to go before beginning to learn. The earth is under our feet; let us direct our attention to it and see what facts may be observed. These will be *geological* facts. Every fact learned by observing the earth is part of the science; and the things observed near home are just as real science, and just as important, as those in distant lands, of which we may read in the books.

Now, first of all, we see that the surface of the earth is covered by a bed of loose materials consisting chiefly of sand, gravel, small stones, and clay. We will call these materials *Drift*, for a reason which will be understood hereafter. The uppermost layer, which is known as *soil*, is generally of a darker color and evidently contains some other substance. We observe the color darkest, and the depth of the soil greatest in places where most vegetable material goes to decay; as, for instance, where many leaves accumulate from year to year, or where grasses or mosses have grown abundantly and decayed, as in low meadows and swamps. In some situations the soil is mostly or wholly composed of substances forming a fine dark mould, with very little gravelly or sandy material derived from the Drift. We also observe that least soil exists in situations where least vegetable matter has decayed, as on dry knolls and along sterile slopes, where the *bed rock* comes near the surface. It is a fair inference from these observations that the matter which imparts a darker color to the upper layer of the Drift is of a vegetable character.

Should it happen that our observations begin in a *prairie* region, like that of central and northern Illinois, we should notice a great depth of dark soil, indicating that vegetation must have grown over the surface with extraordinary luxuriance. What we notice of the native plants or the growing crops quite justifies the inference. We observe, too, that the land is nearly level, and therefore, the matters resulting from vegetable decay have lain on the spot where they grew, and have not been washed away by flowing water. Those who dig wells on the prairies find that underneath the deep soil the material is finer than the subsoil of most other regions, and has different colors. There are very few pebbles or cobble stones either in the soil or the subsoil. This prairie deposit must, therefore, have been produced in a different way from the common Drift of other regions.

But now we visit some locality where a deep excavation has been sunk, and find that the prairie deposit does not continue down to the bed rock. At the depth of thirty, fifty, or a hundred feet we reach the bottom of it; and then comes, generally, something like the real Drift of other regions. We examine it carefully. There are the same sand and gravel, the same rounded stones, as make up the Drift elsewhere. It cannot be distinguished from the Drift. It is the Drift. So we feel authorized to draw another inference. The real Drift was laid down over much of the prairie region the same as over other regions. Then, afterward, by some means the fine prairie deposit was laid down.

But by far the greatest number of us who set out to view the surface of the earth must walk over the common Drift. This is something so nearly alike from New England to the Mississippi River, and from Hudson's Bay to the Ohio, that persons everywhere will see nearly the same things. So, wherever, within the region indicated, you may begin this study, you will be able to observe the geological facts which I now intend to point out.

The surface of the Drift, as you have noticed, is generally rolling. There are hills and ridges and valleys. The streams flow along the valleys, and they seem to have been agencies in the making of the valleys. The forms of the hills are rounded, and it is easy to understand that these have been shaped by the rains. We notice, however, that many of the Drift hills are elongated, more or less, and it is a curious fact that in any particular region their longer diameters are all turned in the same direction. There must be some explanation of this, and we shall try and discover it.

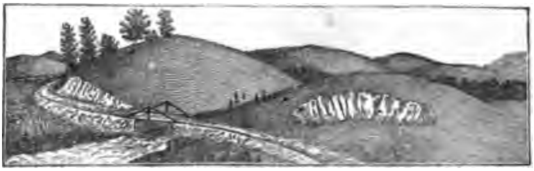


FIG. 5.—DRIFT HILLS IN WISCONSIN. (Chamberlin.) See, also, Fig. 357.

When we examine the materials of the Drift, we notice that it is composed mostly of sand, fine and coarse, with occasional beds of clay. There are many stones, large and small, and they are all rounded. We shall call them all *bowlders*. When they are not over six or eight inches in diameter they are known as *cobble stones*, and are used for rough paving. When they are an inch or less in diameter, down to the size of *gravel*, we call them *pebbles*. They are used with gravel and sand in road making, and also, mixed with asphaltum or coal tar, in sidewalks. Bowlders of all sizes are generally dispersed through the Drift; but the larger bowlders are by no means uniformly dispersed. Many extensive fields are entirely free from them, while in others they form a serious obstruction to cultivation. Here is a view of a bowlder-covered field near Gloucester, Mass. (Fig. 6.)

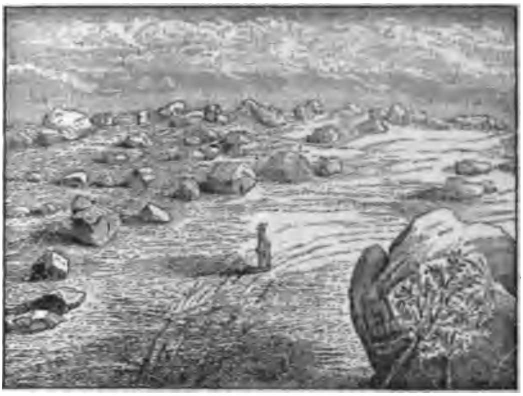


FIG. 6.—A BOWLDER-COVERED FIELD NEAR SQUAM, IN GLOUCESTER, MASS. (After E. Hitchcock.)

In some parts of the country where the bed rock is completely buried by Drift, large bowlders are broken up and used for building stones. They present a substantial and pleasing appearance.

The arrangement of the Drift materials will be noted. If we go to any railroad cut through the Drift, we see beds of sand and gravel laid down without any general uniformity. The beds present a variety of inclinations, and within the limits of a single bed the thinner layers, or *laminæ*, are often seen to pass obliquely

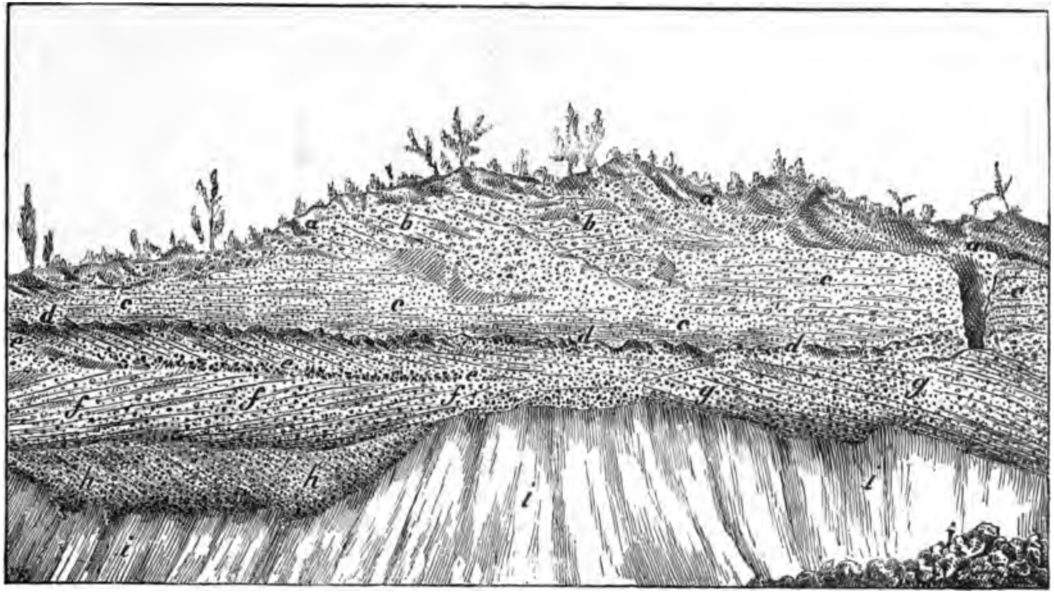


FIG. 7.—SECTION IN DRIFT, "CUP AND SAUCER HILL," ANN ARBOR, MICH.

across. Fig. 7 presents a view of a gravel bank cut through in the construction of a street. Underneath the soil and subsoil, *a a a a*, we notice some gravelly beds, *b b b*, presenting a confused and oblique *stratification*. These are followed by horizontally stratified sand, *c c c c*, and two courses of pebbles, *d d d* and *e e e*, separated by a stratum of pebbly sand which is obliquely *laminated*. Still lower is another bed of gravel, *f f f*, distinctly laminated, but in the other direction. This passes, toward the right, into another bed, *g g*, with *laminæ* inclining to the right. At *h h* is another *stratum* of fine buffish sand with lamination inclined steeply to the right. At the foot of the bank is a sloping pile of sand, *i i*, which has run down from above.

This fine example of a gravel bluff simply illustrates what may be found on almost every square mile of the northern states. This view is 129 feet above the bed of the Huron River, and 304 feet above the bed rock, which has only been reached by boring. On the bed rock the Drift is found to be a heavy mass of *unstratified* clay, with many large bowlders dispersed through it. At other localities this bottom bowlder clay is found exposed at the surface. Sometimes the materials are so firmly packed together that digging in them is difficult. This is the nature of *hard-pan*. When a wide extent of hard pan or clay underlies a level region and is near the surface, it arrests the downward escape of the rains, and gives rise to a marshy district.

Hereafter we shall return to a more careful study of Drift arrangement, and shall try to ascertain how the materials were produced, and how they were spread so extensively over the country.

EXERCISES.*

State some geological fact observed by yourself. What other geological facts can you mention? Is there any hill of Drift materials near your residence? Is there any hill not formed of Drift materials? State how the Drift hill appears to be made up. State what cuts or excavations have been made in it. Did you observe any sort of stratification in it? What is the color of the sand? Is the sand coarse or fine? Can you name any hill or place where clay appears? Does the bed rock come to the surface in your neighborhood? Is the bed rock reached in digging wells? If so, does the water come out of the rock or from the Drift? Does the bed rock belong to the Drift? Mention some valley which is sunken in the Drift. Mention some steep bank along the valley. Mention a bank or hill not covered by vegetation. Where is sand obtained for making mortar? What is the difference between sand and gravel? Mention some prairie region. Is it level or hilly? What sort of material lies at the surface of a prairie? Why does not Drift lie on the surface?

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* To the Student.—The "Exercises" in this book are *not* questions on the text but rather *applications* of the principles, and generalizations from facts stated in the text. They are intended to stimulate thought. Some may be too difficult to answer at present—too difficult even for the teacher. Do not let this produce any feeling of dis-

STUDY II.—*Springs and Wells.*

I suppose you remember the little pond, where the water rests in a little basin of earth and never leaks out at the bottom. What holds the water? If you dig a hole in the garden and fill it with water, the water soon disappears. It soaks into the ground. But if you cover the bottom and sides with a coat of clay, the water is retained. You may have seen little duck ponds made in this way. It is a layer of clay which holds the water in the little lakelet in the field. Clay is so fine and compact that it is almost impervious to water.

Suppose the little pond filled with sand and gravel. Now we have a basin of loose materials completely saturated with water, and the clay bed beneath prevents the water from escaping. The surface of the materials is wet; the water is stagnant. After a time some decaying vegetable matter may accumulate on it, and grasses and sedges may take root, and we shall have a *marsh.* Nearly all marshes and swamps are simply accumulations of sand, gravel, and soil, which are kept saturated with water because a bed of clay or hard pan underlies and prevents the water from soaking away.

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couragement. If you answer half of these questions you do well. With a little reflection you will answer more. It will be all the more useful if some research is necessary, or if the question has to be pondered over several days or weeks. He is the most meritorious student, however, who succeeds in explaining the greatest number of points presented.

Of course there is a raised rim around this basin. From the level of the marsh the Drift surface slopes upward on all sides. Let us now dig a ditch through the Drift border of the swamp, and give it a slight descent toward the nearest stream of water. Now the water drains from the swamp, and the land becomes sufficiently dry for cultivation. Now the swamp may be plowed and planted to corn. The basin of the swamp still collects the rains, but the ditch continually carries away the excess. If the ditch were covered, we should see the water only at its place of exit, and we might consider it a *spring*.

On the hill slope is a spring, which is nothing but the mouth of a covered ditch or drain conveying the water from some saturated bed of porous materials concealed beneath the fields. How steadily it flows! How limpid and cool and refreshing is the stream! It glides down the bank, and is soon joined by several other streamlets fed by other springs along the same hill slope. All together they form a pretty little brook, which flows through the meadows and pasture lands for many a mile. And all along its course the grateful cattle slake their thirst from the cool stream.

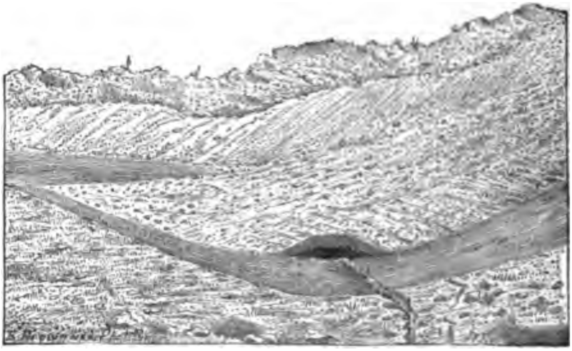

FIG. 8.—SPRING ISSUING FROM A BANK OF DRIFT.

Let us go back to the hillside spring. Here, Fig. 8, is a cut which shows the various beds of sand, gravel, and clay which form the Drift hill from which the water issues. Here is the soil at the top with its vegetation, and underneath are the common Drift materials presenting their usual imperfect stratification, their oblique lamination, and their abrupt limitations. It is the same thing as seen in the Drift section in Fig. 7. Only here is a bed of clay. It is from the upper surface of the clay that the water issues. This bed of clay extends back into the hill an unknown distance. It may be a quarter of a mile or more. It may be even a mile or several miles. Generally, however, all the Drift beds have but very limited extent. Now, in this case, the rain which falls upon the fields percolates downward through the sand and gravel beds, but is arrested by the clay bed. Then the water flows over the surface of the clay bed in the direction of its slope, and that happens to bring it to a place of *outcrop* on the hillside. The clay bed is like a basin to hold the water, though it may be filled with sand. If the basin is flat, or very shallow, we have a broad sheet of sand saturated with water ready to flow off wherever its margin reaches a hill slope. If the basin is depressed like a trough, the most abundant flow is along the trough. If the hill slope cuts across the trough, then the movement of the considerable stream may wash out some of the sand, and leave a real underground passage, along which flows a subterranean stream. The case shown in Fig. 8 is much like this.

Now, evidently, if the water basin extends back under the land, it is possible for the farmer whose house is too elevated to have a spring to dig down to the basin of water which supplies the spring. This is a *well*. Wherever an excavation is sunk to a bed of sand resting on a clay stratum, there water will be found. But no one can tell certainly the depth at which the clay stratum will be reached. In some places it is so near the surface that even a common cellar reaches the water. In other places it lies at a depth of fifty, eighty, or one hundred feet; and the well would be too deep for use. But remember that it is not everywhere the same clay stratum which arrests the water. As these Drift beds are of very limited extent, no one can be certain of reaching water at the same depth as in another well but a few rods distant. Nor does the height of the ground indicate anything in reference to the depth of the water-bearing stratum. All these things are illustrated in the adjoining cut, Fig. 9.

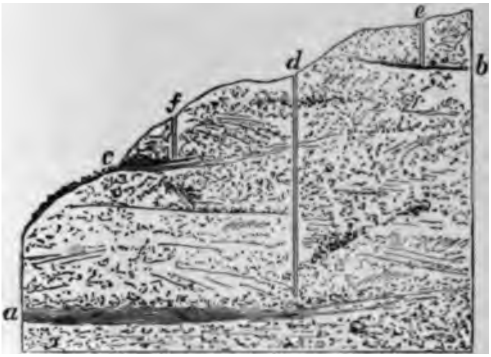

FIG. 9.—DEEP AND SHALLOW WELLS.

Here *a*, *b*, *c* are clay beds, each of limited extent, and each overlaid by a sandy bed which receives water by percolation from the surface. The descending water which is arrested by *c* is conveyed to an outcrop on the hill slope, where it escapes as a spring and continues its descent. That which is arrested by *a* and *b* spreads laterally, and after the basins are full it overflows and descends to still lower basins. At *e* the basin *b* is reached by digging ten or fifteen feet. At *d*, which is but a few rods distant, and is also at a lower level, the well must be sunk fifty feet to reach the water basin *a*.

Probably the water in basins *a* and *b* finds outlet somewhere in springs. It may be directly from these basins, or it may be from other basins into which these overflow. The fact that a basin supplies one or many springs does not prevent its supplying wells also. An excavation sunk at *f* would result in a well, though the spring or range of springs from the basin *c* may not be far away.

Spring and well waters are not absolutely pure. Remember that these waters came from the surface of the land, and must have dissolved and carried away as much as possible both from the surface and from beneath the surface. You can easily imagine that some well and spring waters are notably impure and unhealthy. Some villages and cities have been so poisoned by water which seemed to possess a sparkling purity that deadly epidemics have been occasioned. In many an instance the mysterious deaths of the inmates of an isolated dwelling — even a farm dwelling in the midst of the country air — have been traced to impurity of well water infected by drainage from the surface. Geologically speaking, however, we are most interested in the mineral substances dissolved by subterranean waters and supplied to wells and springs. The most frequently occurring are compounds of lime and iron. The Drift sands abound in them; the waters dissolve them, and escaping to the surface redeposit them. A common compound of lime thus deposited is of the nature of chalk and limestone. It is deposited because the water escaping to the surface and relieved of its pressure cannot hold as much as while underground. When the deposit takes place in standing water, it forms a soft, white substance called *marl.* When deposited over the surface of dry ground, it builds up a layer of *travertin*, which is like a rock, and in France and Italy has been employed extensively for building purposes. When, in flowing over the surface, the deposit incrusts mosses, leaves, sticks, or bones, cementing them in a stony mass, it is commonly called calcareous *tufa.*

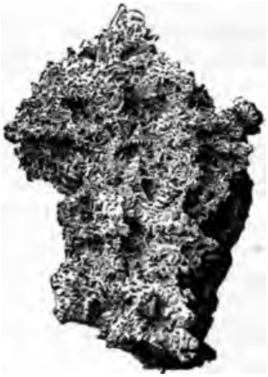

FIG. 10.—PETRIFIED MOSS.

Iron deposits are formed in a similar way. When the iron compound saturates the materials of a swamp, it forms *bog iron ore,* and may possess any percentage of iron, according to the copiousness and duration of the deposition. Bog ores in some places exist in such abundance and purity that iron is manufactured from them. Indeed, it is not unlikely, as we shall see, that the great workable beds of iron ore were originally mere iron-soaked bogs. A similar compound of manganese is sometimes deposited in low grounds in a similar way. This product is black, and is known as *wad* or *bog manganese.* Both bog ores are employed as paint. The bog iron gives us *ochre,* and the bog manganese a black pigment much used in carriage painting. Waters holding limestone in solution are "hard." Those holding iron are said to be *ferruginous,* and often leave a rusty deposit on the surfaces which they bathe. Ferruginous spring waters are often described as *chalybeate.* Many of them possess valuable medicinal properties.

EXERCISES.

Describe the situation of the finest spring known to you. What deposits, if any, does the water leave? Does it produce any rusty stain? State where some travertin or calcareous tufa may be found. When moss is petrified, does the substance of the moss necessarily remain? What becomes of it if not remaining? What is the cause of the white deposit in the bottom of the tea kettle? What sort of water must be used to prevent it? What would be the effect of hard water upon steam boilers? Suppose water holding limestone in solution percolates through a bed of gravel, what happens to the gravel after a time? Could iron compounds be used to produce the same result? Name some well which is much shallower than a neighboring well. Suppose the Drift were all sand, how would the existence of springs be a Where would the surface water all go? What would be the effect on of water? Mention a region where the surface materials are all sand. A streams of water plentiful there? Did you ever hear of a river in the ground? After such a disappearance would it be possible for t river to reappear? Search on the map of Asia or Africa and point out riv which terminate on the land. Suppose the Drift were all clay, how w the existence of springs be affected?

STUDY III.—*Bowlders.*

Let us return to the bowlders. Except over the prairie regions we find them generally distributed. Multitudes of them may be seen upon the surface, and almost every excavation reveals them buried beneath the surface to depths as great as are reached by the Drift formation. In limited districts the Drift is restricted chiefly to sand or to clay; and the uses to which bowlders are applied are diminishing the number in sight. Still, it is no uncommon thing to see them clustered as thickly as is shown in Fig. 6. Bowlders, in some instances, retain enormous dimensions. Several notable cases have been cited by the geologists of New Hampshire, and one of these is reproduced in the adjoining illustration, Fig. 11. This lies near Gilsum, New Hampshire. It is 46 feet long, 24 feet wide, and 26 feet high. It is so large that a country school house is almost hidden behind it. In 1817 an enormous piece was split off by the action of frost. The piece was 33 feet long and 10 feet wide. The whole stone, before the splitting, contained 32,000 cubic feet, and weighed 2,286 tons. A thousand miles from here, on the south shore of Lake Superior, are other enormous bowlders, some of which are shown in Fig. 12. The larger one is of porphyry, and lies twenty-five feet high. As with all bowlders, its angles have been rounded off. We must endeavor, in due time, to ascertain the cause of this. One of the largest bowlders known lies in the Northwest Territory, north of Montana. It is of quartzite, and according to G. M. Dawson, the portion above ground is 40×40×20 feet. Another one is 40×30×22 feet.

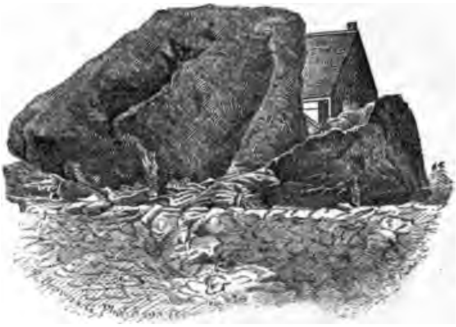

FIG. 11.—GREAT BOWLDER NEAR GILSUM, N. H. (C. H. Hitchcock.)

One peculiar circumstance connected with nearly all bowlders, large or small, is their hardness. This is so notorious that, in allusion to their hardness and roundness, they are very generally known as "hard-heads." Occasionally we find a real bowlder soft enough to be scratched with a knife. Some, also, are in a state of progressive disintegration. In the course of time they will be reduced to sand and mingled with the other constituents of the soil. This suggests that many bowlders must already have been completely disintegrated, and that the finer constituents of the Drift have probably been derived from decaying rocks. It suggests, further, that if these bowlders were ever angular, the simple process of decay would have removed their angles, and reduced them to their present rounded forms. We must keep this possibility in mind.

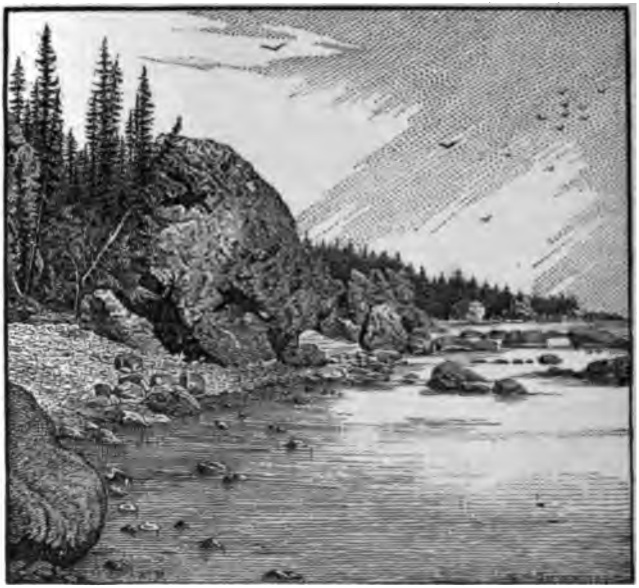

FIG. 12.—GREAT BOWLDER OF PORPHYRY AT ST. IGNACE, LAKE SUPERIOR.

Everyone has noticed the accumulation of bowlders along certain beaches and points exposed to the action of the waves. This is not because bowlders are transported to such situations and laid down. It is because the Drift abounds in bowlders, and in the exposed situations mentioned, the waves wash out the sand and pebbles, leaving the bowlders to settle together close by the water's edge. Innumerable bowlder points may be seen along the coast of New England. One interesting example is at Gay Head, on Martha's Vineyard. The Great Lakes exert a wave action almost equal to that of the sea, and similar bowlder beaches may be witnessed at Keweenaw Point, Lake Superior, at Point Waugoshance, Lake Michigan, and a hundred other localities. The curious phenomenon of "walled lakes" finds its explanation here. Many small lakes in the northwestern states exhibit a rude sloping wall of bowlders forming the beach on one or more sides. Human fancy has sometimes attributed these walls to the agency of the Indians or their predecessors, or even to a race of giants. We have only to conceive the original sandy beach filled with bowlders, and the easily movable sand washed out by the action of the waves, to understand that the bowlders would gradually settle together into the position of a rude sloping wall.

Almost every neighborhood in the northwestern states is in possession of one or more pieces of metallic copper discovered in the Drift. These are real bowlders. They bear the same evidences of wear as the stones. They have apparently been subjected to the same ordeal as the other constituents of the formation of which they are a part. These are examples of native copper. But native copper is not known to exist in all the country except in the region of Lake Superior. As it would not seem reasonable to regard these Drift specimens as produced where we find them, the theory is suggested that they have been brought from Lake Superior. Now, in the same connection you must have noticed that nearly all our bowlders are unlike any rocks found *in place* at points nearer than the shores of the Upper Lakes. All these indications point toward the far north as the region whence our Drift materials have been derived. We may further conclude that they would not have been transported from the far north without exposure to much wear, which would have reduced their volume, rounded their angles, and produced an abundance of fine material. These inferences must be borne in mind when we come to theorize about the agency which effected the transportation of so enormous a quantity of stones and sand.

A more attentive inspection of particular bowlders shows that very few are entirely homogeneous. You must by all means make the examination for yourself. A good many presenting a light-colored or pinkish appearance are nearly homogeneous; but most of these, on close inspection, seem to be formed of grains more or less closely compacted together; and they contain, also, an occasional grain or streak or blotch of a different color. Some dark-bluish or blackish bowlders also appear to the naked eye as almost homogeneous. Close inspection, however, especially with a magnifier, shows that they are finely granular. Most of these reveal, also, a *stratified structure;* that is, lines or streaks or bands of slightly varying character extend in parallel directions across the surface of the stone. They indicate that the whole stone is composed of layers or *strata* which slightly differ from each other in color or fineness.

Most of the bowlders, however, are distinctly heterogeneous in constitution. This is shown by the different colors of the materials. Generally each different color indicates a different *mineral.* Most bowlders contain two or three different minerals, as you will immediately observe. Some contain even more. Now, the name of a rock depends on the minerals of which it is composed. Hence, to determine the minerals must be our first study. If the minerals are promiscuously and somewhat equally distributed, the rock is not stratified; it is *massive.* Unequal distribution sometimes exists in a massive rock, but the materials are not disposed in parallel planes. When they are so disposed we may know the rock is stratified. But these various layers are not to be taken as strata; they are laminæ if they cohere together. Strata are indicated by the separation of a rock into distinct beds. If the strata are nearly a foot thick or over, the rock is *thick-bedded.* We shall use the term *schistose* for thin-bedded rocks. The lamination of a rock is often in the same direction as the bedding or stratification; but sometimes it crosses the bedding. Besides the minerals which make up the principal bulk of the rock, you will often discover one or more other kinds to a sparing extent. These minerals differ generally in color and also in *lustre*, *transparency*, *hardness*, and *crystalline form*. What we mean by lustre will be understood when you compare a piece of glass with pearl or polished steel. The broken surface of the glass reflects light perfectly, brilliantly. A reflecting surface of pearl is less perfect; the light from it is softer. As to lustre, the *glassy*, the *pearly*, and the *metallic* are the most important distinctions to make. Some minerals, also, are *transparent*, like glass; others are *translucent*, permitting light to pass imperfectly, though nothing can be definitely seen through them. Others are *opaque*. In ordinary bowlders nearly all the minerals are hard, but with a tester you will readily discover that some are more easily scratched than others, and some cannot be scratched at all. As to crystalline form, nothing can be made out in some cases; but in others we can discern a line or an angle, or a plane, if nothing more. Even so much indicates that a crystalline form belongs to the mineral, and often gives a very important clew.

There is one other particular in which minerals differ from each other. It is very important, but the distinctions generally cannot be detected without making experiments too nice and elaborate for us to undertake. They differ in *chemical* composition. The ultimate substances of which they are composed are different in the relative proportions in which they exist. One simple test may always be applied by us; we may observe whether effervescence is caused by an acid; but beyond this we must take the statements of the chemists who have the requisite appliances for making chemical analyses. Accomplished mineralogists must themselves be chemists; and it is their practice to employ an outfit more or less portable for making analyses in the *dry way;* that is, without making a solution of the mineral to be tested. They make use of a *blow-pipe* and mostly dry *re-agents*, in the flame of a lamp or gas jet. But though we cannot undertake analyses for ourselves, it is indispensable to understand something of the chemical constitution of minerals; and, therefore, before we proceed farther we must explain the rudimentary principles of chemistry.

EXERCISES.

What very large bowlder have you ever seen? What is its color as nearly as you remember? Is it homogeneous, or is it composed of different minerals? Have you ever noticed the distinction between stratified and unstratified bowlders? Here are fragments of rocks obtained by breaking up several different sorts of bowlders; pick out one which is homogeneous. Pick out one which is heterogeneous. How many kinds of minerals in the last? Pick out one having a massive structure. One having a schistose structure. One with a thick-bedded structure. Has the latter any laminæ? Pick out a specimen showing laminæ. What distinguishes the laminæ from each other? What different colors or forms of minerals can you distinguish in it? Put all the massive specimens in a pile together. Put all the stratified specimens together. Are there any homogeneous rocks in the last pile? [The teacher will frame a large number of similar exercises.]

STUDY IV.—*A Little Chemistry.*

It is generally believed that all matter is composed of or portions so small that they are never divided and can t divided. The finest dust floating in the air is coarse in com son. The atoms are so minute that they are not only inv le a beam of light, but also under the most powerful micros An impressive idea of their minuteness may be gained by ing that if a drop of water could be enlarged to the size of earth, the atoms of which it is composed, each enlarged in same proportion, would be about the size of small shot. Of s inconceivably minute parts are all substances composed. I stones, water, and air consist alike of ultimate atoms,

Now let us follow our chemical teachers. Among these billions of billions of atoms there are held to be about sixty-four different sorts. There is one kind of atom in iron, another in gold, another in sulphur. Some atoms appear to be much more abundant than others. If we take an average sample of the solid part of the earth weighing one hundred pounds, it will be chiefly made up of the atoms or elements named below, and in about the proportions stated :

Oxygen	45 pounds.	Carbon	All together nearly 1½ pounds.
Silicon	25 "	Hydrogen	
Aluminum	10 "	Sulphur	
Iron	8 "	Nitrogen	
Calcium	6 "	Chlorine	
Sodium	2½ "	Magnesium	
Potassium	2 "		

In the atmosphere and in water there are larger proportions of Nitrogen, Oxygen, and Hydrogen. A vast number of atoms of the same kind brought together forms a visible amount of the substance. Some substances are solid, others are liquid or gaseous at ordinary temperatures, and under other ordinary conditions. But it has been shown that heat will liquefy, and even vaporize, all solid substances, while cold and increased pressure will liquefy, and even solidify, all gases.

All the atoms have a tendency to come into close union with other atoms, and to remain so united. This tendency is commonly known as *chemical affinity.* The union so formed is a chemical compound. Nearly all the other atoms have affinity for the atom called oxygen. The compound resulting from the union of oxygen with another element is termed an *oxide.* Thus iron and oxygen form *iron oxide,* or oxide of iron. Silicon and oxygen form *silicon oxide;* aluminum and oxygen, *aluminum oxide.* So chlorine, bromine, iodine, and sulphur united with other substances form *chlorides, bromides, iodides,* and *sulphides.* Many of these compounds are commonly known by other than their chemical names. Thus, one iron oxide is simple iron rust; hydrogen oxide is water; calcium oxide is lime; sodium oxide is caustic soda; potassium oxide is caustic potash; silicon oxide is silica, or quartz; sodium chloride is common salt; iron sulphide is pyrite. Some compounds contain two, three, or more times as much oxygen, or chlorine, or sulphur as others; but we shall not here observe the distinctions.

Now, a very important chemical principle is this: Oxygen united with certain substances produces *acid-forming oxides;* while with other substances it forms *basic oxides.* The addition of hydrogen to an acid-forming oxide makes an ac of the acids most important for us end in *ic*. Th acid, or "oil of vitriol," is composed of sulphur, oxy drogen. Nitric acid is composed of nitrogen, oxygen, gen. The basic oxides generally have names which Many of them have also old, popular names, as before t

Another important principle is this: The acids e tendencies to form compounds with the bases. Such c are *salts*; and if the name of the acid end in *ic*, the of salt ends in *ate*. Thus, sulphuric acid and soda form sod phate, or according to the old nomenclature, still much phate of soda. Silicic acid and lime form calcium e, silicate of lime; carbonic acid and lime form calcium b or carbonate of lime, which is familiarly known as li chalk, and marl. The latter, however, commonly cont mixture of clay.

A third important principle is this: The affinities of d substances for the same substance are not all equal. Sul acid, for instance, has a stronger affinity for lime than acid has. Hence, when sulphuric acid is brought into with carbonate of lime, the carbonic acid is driven off, and sulphuric acid takes its place, forming sulphate of lime. All mineral acids will do the same, forming each its appropriate of lime. Even strong organic acids, like pure vinegar or a acid, will drive carbonic acid away from carbonate of lime. carbonic acid is a gas (called also carbon dioxide), it assumes form of a gas instantly on being compelled to dissolve its uni with the lime. The gas is much more bulky than the carbonate, and, accordingly, it forms numerous small bubbles with the liquid acid which remains uncombined. This phenomenon is called *effervescence.* The demonstration of effervescence, as illustrative of this selective action among acids and bases, is quite within the reach of our simple resources. Take a bit of chalk and apply a drop of any strong acid to the surface, and effervescence instantly ensues. The effervescence shows that carbonic acid was one of the constitutents of the chalk. Strong vinegar will produce effervescence. The same result follows if marl or limestone is employed; hence, these are shown to be carbonates.

A fourth important principle is this: Heat weakens the strength of the union formed between two or more substances. We have just seen that limestone is carbonate of lime — that is, a union between lime and carbonic acid. Now, if we subject limestone to a red heat, the union between the acid and the base is not only weakened, it is destroyed. The carbonic acid rises into the atmosphere, and the lime remains. Simple lime is known as *quicklime*, or caustic lime. But, after cooling, it is eager to regain a supply of carbonic acid, or other acid, and it slowly absorbs that gas from the atmosphere. If we dissolve quicklime in water, and pour off the clear fluid standing over the excess of lime, we have lime-water. This eagerly unites with or neutralizes any acid with which it comes in contact. Hence it is employed to correct "acidity of stomach." If now we breathe into the lime-water through a straw or a glass tube, the carbonic acid from the lungs unites with the lime in solution and forms a white cloud, because the carbonate of lime resulting is not much soluble, and remains as an infinitude of minute white particles. These slowly settle to the bottom and form a white, chalky powder, known as *precipitated chalk*. This also is used by physicians as an antacid.

Should we pour slowly a quantity of lime-water over a pile of sand, it is obvious that the carbonate of lime would be formed in the interstices between the particles, and might finally fill them up. The grains of sand would then be firmly cemented together by a calcareous cement. We shall find many rocks thus cemented. The application of a drop of acid then produces slight effervescence, which reveals the nature of the cement.

Intense heat is capable of dissolving very many unions — not alone between acids and bases, but between oxygen and other substances. It is probable indeed, that a degree of heat is possible which would reduce all substances to their ultimate elements. In such a heat, no compounds could exist. This state of matter is known as *dissociation* and the facts are connected with theories of the primeval condition of the world.

Thus it appears that nearly all substances known to chemical compounds. Minerals are chemical compoun greater part. Certain metals only, in the native , elementary or uncompounded. Gold, silver and copper but nearly all metals, as well as other substances, ve into combinations as oxides or chlorides, or sulphides, or ates and other salts. It is an important fact that every cl compound tends always to form crystals of the same fund form. That is, it will form solids always of the same o r (rhombohedron, hexagonal prism, etc.), and always ha sides so inclined to each other as to form the same a then, for instance, we have learned by observation what geometrical solids is formed by calcium carbonate, and values of the angles, and then find an unknown mineral of same geometrical form, and having the same angles, it is r-fectly safe to conclude that the unknown mineral is calcium bonate. That is, its chemical composition is shown by its cy l-line form. In the determination of minerals, theref detection of the crystalline form is always desirable. By a of the form, the hardness, the color, the lustre and the gravity, we may generally make a determination of the com minerals. Knowing the mineral, we know the chemical sub in it. All that we shall at present attempt is the determ of the common minerals entering into the formation of the mon rocks; and we shall attempt this almost wholly by an i tion of their physical characters.

EXERCISES.

What is the acid in carbonate of potash? Of what is chloride of calcium composed? What is the composition of lime? Name some substances which are elementary. Name some containing oxygen. Why cannot the atoms of matter be seen under the microscope? Are the atoms infinitely small? Did you ever notice a calcareous incrustation on stones in a pond or lake? How might it be explained? Why is it not a pure white, like chalk? Name some acid which has a strong affinity for lime. Name one having a feebler affinity. What would be a relief to acidity of the stomach? What would result if pulverized marble were thrown into a vessel of vinegar? If vinegar is acetic acid, what salt would be formed? If you take one hundred grains of the average solid earth, how many grains of silicon might be extracted from it? How many grains of potassium? State, if you can, what elements are most abundant in vegetation. What is the principal source of carbon in plants?

STUDY V.—*Quartz and Feldspar.*

We are now prepared to begin the investigation of common minerals. Let us select a common bowlder and break it into so many pieces that *each of us shall have one fragment* of convenient size to hold in the hand and inspect. The collection of these specimens may have been done beforehand; or we may proceed together to the field and procure the specimens as we need them. The best bowlder to begin on will be one containing several minerals. This will be indicated by the various colors — though sometimes various colors result merely from different varieties of the same mineral, as we shall see.

Now, with our specimens in hand, suppose one or more of the minerals is nearly white; and suppose another reddish, and another quite dark colored. Look attentively at the light colored minerals and consider if they seem to be all alike. Test the hardness of several samples of the white mineral, or minerals. Can you make a scratch on them? Yes, you say, your implement leaves a dark metallic mark. That is not a scratch of the mineral. It shows that the mineral is harder than the implement. Well as soon as we observe this we may pronounce the mineral *quartz.* This is the hardest of all the common minerals. It is also very abundant. It is not always white, or nearly white. It may be transparent, pink, red, smoky, or even almost black. But its hardness will always betray its character.

It has another character by which you may almost always detect it. Quartz has a *vitreous* or glassy lustre. This is most conspicuous where the quartz is transparent, but in all ordinary quartz the glassy lustre can be seen.

The quartz minerals thus detected in the bowlder you be generally rounded grains or pebbles. Sometimes, in ed, are so closely compacted together, that the outlines of can scarcely be traced. One would think that some lar rock had been reduced to small fragments, and the f rubbed together until the angles were rounded, and then a c pacted as we see them. But quartz being a simple mineral, crystallizes in a definite form. The separate crystalline b resulting are crystals. The cr of quartz is a *hexagonal* Here, in Fig. 13, you have a view several crystals, larger and l Each has six sides, and the slopes correspond to the *faces*. This is the *termi* unfrequently quartz cry ls c with a termination at each d. T crystal appears to have been fo by progressive additions on all sides; for almost always we see side more built out than But the more a side projects the narrower it is, since the tiguous sides must be preserved in true planes. Good q crystals may sometimes be found in coarse bowlders, especially cavities.

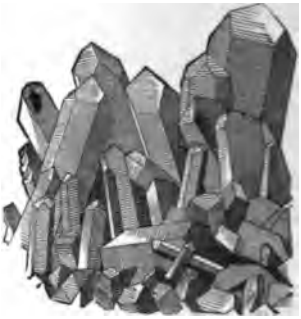
FIG. 13.—A GROUP OF CRYSTALS OF QUARTZ.

Pure quartz is transparent, like glass, and the crystals sent, therefore, a remote resemblance to diamonds. "B pebbles" and "Alaska diamonds" are merely crystalline q Quartz, however, is more commonly mixed with some impuri and it thus loses transparency and acquires color. Violet col quartz is *amethyst*. Quartz so mixed as to have a uniform w lustre rather than a brilliant, glassy lustre is *chalcedony;* v alternating bands of differently colored chalcedony form A chalcedony containing minute mossy patches, of deeper co is a *moss agate*. If the impurities greatly dull the lustre of quartz it becomes *flint*, and if they produce an earthy lustre it *jasper*—red, black, or green. *Chert* is an impure quartz, generally containing lime.

It is most important to know of what quartz is composed. It is its composition which determines all its properties. The chemist tells us that quartz is pure *silica,* and that silica is composed of silicon and oxygen. There are twenty-eight grains of silicon to every thirty-two of oxygen. So you can calculate from the table in Study IV that one hundred pounds of the solid earth contain about fifty-three and six-tenths pounds of silica, or quartz.

Now we will carefully examine and test every part of the rock specimen in hand, to ascertain whether it contains more than one variety of quartz. Very likely we shall discover two varieties—one with more color than the other. One may be nearly transparent, and the other a little reddish or a little dusky. But we must be sure the glassy lustre is also present.

Is there a light-colored mineral present which, with considerable effort, receives a scratch? Is there a pinkish, reddish, or cream-colored mineral which can be scratched? Any mineral of these colors, if so hard as to be scratched *with difficulty,* is probably a *feldspar.* Quartz will scratch feldspar; but feldspar will not scratch quartz. Quartz will always scratch glass. Most glass may also be scratched by feldspar, but not so readily.

There is sometimes difficulty in deciding whether a small grain of a mineral is quartz or feldspar. We had better select rocks at first which are coarse-grained. But sometimes we are compelled to make the determination in a fine-grained rock. Whether fine or coarse, we may proceed next to examine the lustre. Feldspar has a pearly or subvitreous lustre in most cases. If we detect such a lustre instead of the bright, glassy reflection caused by quartz, the question is decided. If we have a doubtful mineral, we must frequently glance at the lustre of an undoubted fragment of quartz, and compare the two lustres. Very often the lustre serves to identify feldspar.

But there is another method. Feldspar fragments often present in the rock distinct flat *faces* or surfaces. Quartz fragments do not. Hence, if, on changing the position of the stone in reference to the light, we see here and there , t appearing and disappearing as they reflect anu o to the light from a window, then we may be pretty feldspar. If, on testing for hardness, one of th a little softer than quartz, the suspicion is confirmed. ll: if the reflecting plane is bounded by a straight line, i plane or face can be seen making nearly a right an wi first one, then we have a final proof, if the other i agree, that the mineral fragment under consideration f

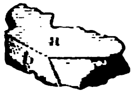

FIG. 14.
FRAGMENT OF FELDSPAR CRYSTAL.

Here in the margin is a cut of a felds f where *a* is one of the reflecting faces and a other; and these join together at a right a , nearly that. This is larger than most of the ments found in the rocks. A common form which feldspar is seen is that of a box partly c by pressure applied in the middle of one end at top and exerted toward the opposite end of the bottom.] the sides remain at right angles with the top and bottom. such forms can only be seen in fragments, and generally w magnifier.

It is often the case that no right angle can be detected. the reflecting surfaces may be present, showing also the pearly subvitreous lustre. But if no faces can be found, the lustre may be there, distinctly less brilliant than in a case broken quartz; and finally, the test for hardness remains to The test of weathering is also valuable. On the weather face the quartz grains retain their glassy lustre; feldspar g weather opaque and earthy, with increased whiteness. In of these various resorts the learner will sometimes feel in whether certain fragments are quartz or feldspar. This good reason for discouragement. Quite possibly the case is difficult one. He may try another rock, and, if possible, a coarser one; or he may keep on repeating the round of tests, and c to the best decision he can.

The geometrical form under which common feldspar crystall is shown in Fig. 15. Here you see the position of the ri angle represented in Fig. 14, since *l ì* is at right angles with *l i* and also with *O*.

We say this is *common* feldspar; since there exist really several species of feldspars, all of which are composed chemically of *silica, alumina,* and an *alkaline constituent,* while they differ according to the nature of that constituent. If to silica and alumina be united potash, the feldspar is *orthoclase,* or common feldspar, the species which gives us most nearly a right angle. This is also called *potash feldspar.* If the alkaline constituent be soda, we have the feldspar known as *albite,* or soda feldspar. If it is lime, we get *anorthite.* If it is soda and lime, we have a soda-lime feldspar, *labradorite,* or *oligoclase.* There are a few other feldspars, but we need not mention them here.

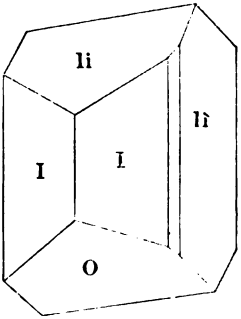

FIG. 15.—LARGE CRYSTAL OF ORTHOCLASE, A SPECIES OF FELDSPAR.

It is important to notice the proportions of silica in the several feldspars, because *acidic* feldspars, or those with much silica, are found in company with other minerals having much silica, and *basic* feldspars, or those poor in silica, seek the company of other basic minerals. Now the acidic feldspars have silica as follows: orthoclase, 65 per cent; albite, 68; and oligoclase, 62 per cent. The basic feldspars have silica as next follows: labradorite, 52; anorthite, 43. (See the Table of Compositions, Study VIII.)

You perceive that the feldspars differ in their composition; but *we* cannot easily test the composition, and therefore we have no certain way for distinguishing them. Hence, sometimes we must simply say the mineral is a feldspar. If we detect the right angle, we may say it is orthoclase. All the other feldspars named may be grouped as *plagioclase* or triclinic feldspars. Of the plagioclase feldspars, *albite* inclines to snowy white; *anorthite* is often glassy and transparent; *labradorite* inclines to gray, brown or greenish, with sometimes a beautiful play of colors in reflected light; *oligoclase* is generally white with a greenish tinge and fine striæ on the principal faces — to be seen with a magnifier. The presence of the colors indicated affords only a first presumption as to the species of plagioclase under investigation. Any plagioclase may show striations. We may safely say: If the right angle is present, the feldspar is orthoclase; if striæ are present it is a plagioclase; if the feldspar is glassy it is very probably a plagioclase; if it is cream-colored or reddish it is probably orthoclase; if dusky or greenish, or with internal reflections, it is probably plagioclase. Orthoclase, also, undergoes less change from weathering than plagioclase; and it is found more commonly in the company of quartz.

Here is a table in which the characters are presented another way:

Name of Feldspar.		Alkaline Constituent.	Leading Colors.	Transparency.
Orthoclase.		Potash.	White, creamy, gray, flesh-red.	Translucent, opaque. Rarely transparent.
Microcline.		Potash—Soda.	Like orthoclase, or green.	Translucent.
Plagioclase or Triclinic. Often striated.	Albite.	Soda.	White rarely bluish, gray, reddish, greenish.	Transparent to subtranslucent.
	Oligoclase.	Soda—Lime.	Faintly grayish-green, white.	Transparent to subtranslucent.
	Labradorite.	Lime—Soda.	Gray, brown, greenish. Play of colors.	Transparent to subtranslucent.
	Anorthite.	Lime.	White, grayish, reddish.	Transparent to translucent.

By the decomposition of the feldspars we get *kaolin*, which consists chiefly of silica, alumina and water. It is white when pure, and is used in the manufacture of porcelain and china-ware.

EXERCISES.

Have you found any quartz in the specimen in your hand? How varieties of quartz in the specimen? State the color of each variety. Is t any transparent quartz in the specimen? Point out any feldspar in specimen. How do you know it is not quartz? What indication that it is orthoclase or oligoclase? Point out some reflecting faces of feldspar. Have you met with any striated feldspar? Take another bowlder fragment and point out the quartz. Point out the feldspar. How many varieties of quartz can you find in it? How many varieties of feldspar? Point out plagioclase if any. Practice holding different specimens in such way as to catch the feldspar reflections. Notice again and again the difference between the lustre of feldspar and that of quartz. Search many different specimens from different bowlders for varieties of feldspar, and particularly for striated feldspars. Do you often find orthoclase and plagioclase in the same bowlder? What are commonest colors of feldspar, according to your observation? Does quartz break with smooth faces, like feldspar? Which has the most glistening lustre? Have you noticed feldspar fractures with a dull lustre?

OBSERVATION.—The discrimination of feldspar from quartz is sometimes difficult in small grains. But do not be discouraged, for it is difficult sometimes even for the professor. Repeat these and similar exercises very many times. Use the same bowlder fragments and also different ones. Every time you succeed you will feel fresh delight. Every time you fail, form a new resolve. Always study with specimens.

STUDY VI.—*Dark-Colored Minerals.*

Let us examine farther the same rock specimens as before used. We suppose these contain one or more dark-colored minerals. If they do not, we must provide ourselves with specimens from some other bowlder. Among dark minerals disseminated through bowlders, it will be noticed that some occur in thin, mostly shining, *scales*, and others do not. Let us take specimens containing a scaly mineral. It is probably *mica*. With a knife point you may lift up a succession of thin scales from the same fragment. There seems no limit to the capability of splitting. Notice that if the surfaces are brilliant, the scales are generally elastic and tough. But examples long exposed to water and air have mostly lost their elasticity, and have become softer, sometimes easily crushing to a greenish-gray, lustreless powder. When the mica is unaltered there is no difficulty in identifying it; but when much altered it approaches the appearance of some other altered minerals.

Mica, like feldspar, is a generic name; but all the micas are composed of silica, alumina, potash and iron, with some other characterizing constituent. Common mica (so-called) is the species *muscovite.* It splits into thin, tough, flexible, elastic scales. In color it varies from white to gray, brown and pale green. It is sometimes violet, yellow or dark olive green. Bronzy muscovite is sometimes mistaken by the ignorant for gold. The transparent variety is extensively employed in stove doors, and is sometimes ignorantly called "isinglass." By absorption of water, muscovite undergoes the changes already mentioned, and becomes *hydromica,* also called *margarodite.* We find the mineral in all stages of transition to hydromica; and one is often at a loss to decide between the two names. Through the same kind of change it approaches talc and chlorite, as we shall see.

Deep black mica with *splendent* lustre is generally the species called *biotite.* We shall find it more common than muscovite. *Phlogopite* is yellowish-brown, brownish, red (often with copper-red reflections), green, white or colorless. This, also, is quite common. *Lepidolite* or lithia-mica is sometimes seen in delicate pinkish scales. You will endeavor to find in bowlders the different species of mica mentioned.

While speaking of the scaly minerals in our hands, it is b to mention a few which are not micas. We shall meet w t occasionally. Those which we shall mention are all h o silicates of magnesia, except one, with generally other co ents; one of these is *talc,* which is simply a hydrous silicate magnesia — that is, composed of silica, magnesia and w The scales are thin and tender, and not elastic, and their c ranges from apple-green to white or silvery. Talc is the sof of the minerals. The scales are very easily reduced to pow The mineral has a peculiar greasy feel, and this is one means o distinguishing it from some micas; though, as before stat hydromica approaches it. Another mineral called *pyrophyl* is a hydrous silicate of alumina. Thin scales appear much lik talc; but the mineral is chiefly known as the constituent of a fi compact rock used for slate pencils. *Serpentine,* a hydrous sili of alumina, magnesia and iron, is sometimes scaly or foliated, but more frequently fibrous. It is far better known, however, in the massive state as a rock. Its color is leek-green or blackish-green, and like talc it has a greasy feel. Under *chlorite* are included chiefly two foliated minerals which are both hydrous silicates of alumina, magnesia and iron, and both of a greenish color. Of these, *ripidolite* is transparent or translucent, with flexible, somewhat elastic leaves, and *prochlorite* is translucent or opaque, with flexible and inelastic leaves. Keep a watch for these scaly minerals.

This ends the important scaly or foliated minerals. There are, however, two species of dark minerals of much importance, and sometimes we experience difficulty in distinguishing them from dark mica. *Amphibole* is one of these. If you take in hand a bowlder fragment containing some dark mineral which is not mica, the mineral is likely to be *hornblende*, the common variety of amphibole. We can easily provide ourselves with samples of such a rock. We must have them. Now look at this dark mineral, hornblende. It is dark greenish or nearly black. It has a bright lustre, and about the hardness of feldspar. If you scratch it, the *streak* is white or whitish. You can generally detect a crystalline face; and sometimes you find a crystalline form which is like a six or four sided rod, as shown in Fig. 16. Often the surface of the crystal fragment presents a *fibrous* structure. This distinguishes it from black mica.

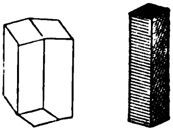
FIG. 16.—CRYSTALS OF HORNBLENDE, THE COMMON VARIETY OF AMPHIBOLE.

Another variety of amphibole is white and fibrous, and this is *tremolite* or *asbestos*. Asbestos somewhat resembles linen, and may be made into cloth which is incombustible. It is used as a non-conductor of heat to wrap around steam boilers and pipes. Still another variety is *actinolite*, consisting of coarser and solider, green radiating fibres or blades. Silica, magnesia, lime, iron, and often alumina are the principal constituents of amphibole. By combining with water, hornblende changes to a soft, greenish mineral resembling hydromica, though not in scales.

The other important species of the dark minerals is *pyroxene*. It closely resembles amphibole, though inclining more to greenish tints. It holds the same constituents, though in different proportions; and has nearly the same crystalline forms and hardness and nearly the same specific gravity. It is not easily distinguished without microscopic or chemical study. In colors, when it varies from green or greenish-black (*augite*, the common variety), it approaches whitish in one direction (*sahlite*) and brownish in the other (*diallage*). It is seldom quite black, while this is a common color with amphibole (in hornblende).* The different natures of hornblende and augite are shown by the fact that hornblende is very often found, like muscovite, in company with quartz, while augite is seldom so found. Their resemblance in crystalline form will be seen by comparing Fig. 17 with Fig. 16. Here the faces *I I* make with each other an angle of 87° 5′, while in hornblende the same faces stand at an angle of 124° 30′. In Fig. 17 this angle is truncated by the plane *i i*. It is seldom, however, that we can detect the angles in the small fragments found in common rocks.

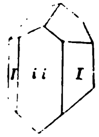

FIG. 17. CRYSTAL OF AUGITE, THE COMMON VARIETY OF PYROXENE.

There are still two minerals, generally dark, or even black, which possess some importance as rock constituents. One of these is *tourmaline*. It is seldom sufficiently abundant to determine the name of a rock, but its presence sometimes necessitates a qualifying epithet. Tourmaline may often be seen in the form of straight, stick-like, shining, black, imperfectly three-sided prisms imbedded in crystalline limestones or quartz rocks, and not unfrequently other kinds of rocks. The common prisms range in size from a twentieth of an inch to half an inch and over. Their sides are curved and generally striated or fluted, with a hardness equal to quartz. Rarer varieties of tourmaline are brown, green, blue, pink, and even white. The mineral contains boric acid, besides silica, alumina, and sundry other constituents in various proportions.

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* In addition to this, augite is frequently found altered to hornblende. In spite of these resemblances between amphibole and pyroxene — especially between the varieties hornblende and augite — it is very desirable for the trained investigator to be able to discriminate between them, since the determination of certain rocks depends on this. Moreover, there are important and deep-seated differences between them, as is shown by their optical and microscopic properties.

The last of the dark minerals worthy of mention is *hypersthene*. This is sometimes a rock constituent in company with labradorite. It occurs in masses of thin, brittle lamellæ of a dark brownish-green, grayish-black, greenish-black, or pinchbeck-brown color, having a hardness nearly equal to orthoclase. It has about the same constituents as amphibole.

EXERCISES.

Take in hand a rock fragment containing a dark mineral, and state whether the mineral is scaly. If so, are the leaves elastic? Are they brittle? What is their color? What proportion of the rock do they form? If not scaly, is the mineral lamellar? Is it fibrous? What is its color? Is it shining or dull in lustre? If the scales were greenish, what mineral would they probably be? Would they then be elastic or not? If whitish, what mineral would they probably be? Would they be elastic or not? Would they be harder or softer than mica? If the scales are jet black, what mica have we? What, if they are reddish? What, if they are bronze-like? What points must be mentioned in describing a mineral? Take another rock specimen, and describe completely the most abundant mineral in it. What light-colored minerals do you see? Pick out a mineral which you think is augite. What particulars lead you to think it augite? Pick out a sample of hornblende. What differences between them can you discern? Which has most quartz associated with it? If a rock contains biotite, is the other dark mineral, if present, likely to be hornblende or augite? Select a rock containing hydromica. Why will not hydromica effervesce? What may hydromica be mistaken for? Explain why the surface rock often contains hydromica and the deep quarry rock muscovite. Did you ever know of a man who collected bowlders containing bronzy mica, thinking this mineral to be gold? Search for specimens of tourmaline. How does tourmaline differ from hornblende? How will you know it when found?

STUDY VII.—*Lime, Magnesia, and Iron Minerals.*

Among important rock ingredients two yet remain to be studied which belong to the group of carbonates. Some of the properties of carbonates have already been learned, especially their tendency to effervesce when strong acids are applied to them. Chalk, we have seen, is a carbonate, but it does not present any crystalline form or lustre. It is simply earthy, and consists of a mass of fine particles of carbonate of lime compacted together. Marble also consists of a mass of grains and particles somewhat cemented; but marble has some lustre. There are shining faces. In fact, a close inspection, especially with a magnifier, shows that the rock is composed of small crystal fragments. Some marbles are sufficiently coarse to show the crystalline structure very distinctly.

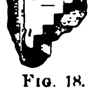


Fig. 18.
Fragment of Crystal of Calcite.

Now we frequently find these crystals sufficiently large to be studied. Let us seek for some white vein running through another rock. We may at first fall upon a vein of white quartz. The tester will determine. Suppose we have found a white mineral or fragment large enough to show crystalline form, and soft enough to be *easily* scratched. Probably this is *calcite.* You cannot, perhaps, discover the complete form; but if you scrutinize closely, you will notice some angles, and you will perceive, probably, a number of cracks which run in directions parallel with the faces revealed. Perhaps the cut, Fig. 18, represents part of what you see. Here is one face *a*, bounded by another face *b*, forming an angle along the line *m n*. This is not a right angle, but is greater or less. You see, also, along the fractured border of *a* several angular saliences, which are bounded on one side by planes exactly parallel with *b*, and on another by planes parallel with each other, and in fact parallel with another face of the broken crystal. The directions of these planes are continued in cracks passing through the crystal. It appears that the crystal is made up of many small crystals, all having the same shape. If we could get one of these crystals out, it would present the form shown in Fig. 19. This form is a rhombohedron. If you take a cubical box and partly crush it by pressing against one corner toward the corner diagonally opposite, you reduce the box to the form of a rhombohedron. Notice particularly the difference between this and common forms of orthoclase.

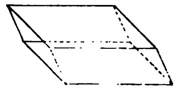


FIG. 19.—CRYSTAL OF CALCITE.

The hardness of this crystal is much less than that of orthoclase; and this furnishes a third easy means of separating the two minerals — effervescence, want of right angle, and lower hardness.

The cracks generally apparent indicate *cleavage* planes, as Fig. 18 shows. Every fragment, therefore, presents the same angles as the whole. Calcite is sometimes as transparent as glass, and then known as *Iceland spar.* It possesses the striking property of double refraction. If you place a plate of Iceland spar on a printed page, you see every letter beneath it double. Calcite is more commonly almost opaque. Its color is nearly always white, but sometimes we find it yellowish, delicate blue, and various other tints. The fundamental rhombohedron is also frequently modified, and the forms resulting are very numerous. The most common, however, is that known as *dog-tooth spar,* of which a couple of large crystals are shown in Fig. 20.

FIG. 20.—DOG-TOOTH SPAR.

We must not conclude too readily that a whitish mineral is calcite, even when soft enough to be cut with a knife. Not unfrequently we encounter crystals having the lustre and hardness of calcite, but with curved faces—opposite ones being convex and concave. Cold dilute acid applied to these does not cause effervescence, even after they are reduced to powder. But heat applied produces it. The chemist informs us that this mineral is composed of carbonate of lime, fifty-four parts, and carbonate of magnesia, forty-six parts. A mineral having this composition is called *dolomite*. This crystal with curved faces is a variety called *pearl spar*, when the color is white, and *brown spar* when the color is brown. The brown coloring ingredient is iron. So manganese or cobalt gives a reddish dolomite.

But when the crystalline faces are *not* curved it is difficult to distinguish dolomite from calcite without chemical analysis. We may find "veins" of coarse dolomite crystals closely resembling calcite veins in color, form, and hardness of the mineral. Our only expedient then is the dilute acid. We shall see that dolomite is a mineral almost as abundant as calcite, and hardly less important.

A rock ingredient belonging to the group of sulphates is very familiar. It is soft enough to be crushed between the teeth. Everyone knows *gypsum*; but pure crystallized gypsum is less common. It occurs in distinct crystals, or broad leaves, or plates, sometimes a yard across, and as transparent as glass. This variety is called *selenite*. One of the crystal plates is shown in Fig. 21. Gypsum is composed of sulphuric acid forty-six and one-half parts, lime thirty-two and one-half parts, and water twenty-one parts. When subjected to heat the water is expelled, and the gypsum is said to be "calcined." When ground gypsum is calcined it constitutes "plaster of Paris"— so called because the quarries at Montmartre, Paris, supplied gypsum for calcination and use in the city. The Paris gypsum, however, contained also carbonate of lime. When calcined gypsum is exposed to water it reunites with a certain amount of water, and resumes a high degree of hardness. In other words, it "sets." It is, therefore, valuable for many purposes.

FIG. 21.—A TRANSPARENT CRYSTAL OF GYPSUM.

There are three principal ores of iron which in some regions exist to a rock-making extent. *Hæmatite* is simply an oxide of iron, composed of two equivalents (or atoms) of iron and three of oxygen. Taking the mineral by weight, one hundred parts of hæmatite contain thirty of oxygen and seventy of iron. This mineral is well known as iron rust. In nature it is often beautifully crystallized, and occurs also in granular and *stalactitic* shapes, and in laminæ, either thick or thin. The crystals have a metallic lustre, and sometimes are truly splendent. Their color is steel gray, or iron black, but scales thin enough to transmit light are blood red. When the surface is shining and mirror-like, the mineral is called "specular" ore. Hæmatite sometimes occurs in thin *micaceous* scales, and frequently in compact *fibrous* masses. When earthy, it becomes *red chalk* and *red ochre.* Hæmatite sometimes attracts the magnetic needle. A neat way of distinguishing hæmatite in any of its varieties is by the *red* color of its powder (called streak). Powdered hæmatite is, therefore, red, and is much used as a *red paint.*

Limonite is simply hæmatite which has united with water. It contains sesquioxide of iron, eighty-six parts, and water, fourteen parts, in one hundred. The eighty-six parts of the sesquioxide contain twenty-six parts of oxygen and sixty parts of iron. We find limonite commonly in stalactitic or botryoidal forms—the latter like bunches of grapes—and having a fibrous structure. These forms often possess a nearly black, glaze-like exterior. In the mines at Salisbury, Conn., Amenia, N. Y., and in many other localities, the cavities of the rocks often contain groups of brilliant black, icicle-like columns of limonite depending from the roof or reaching quite to the floor of the cavity. In other situations this ore is earthy, and constitutes ordinary *yellow ochre.* This is the iron deposit of bogs, where it forms *bog iron ore,* of which we have before spoken (page 11). Limonite is easily distinguished by its *yellow* or *yellowish-brown* streak.

Magnetite, the third important ore of iron, is known by its ***black streak.*** It is a mixture of the two principal oxides of iron—protoxide (or one of oxygen and one of iron), and sesquioxide (or three of oxygen and two of iron). The amount of oxygen in one hundred parts by weight is twenty-eight parts, and the amount of iron seventy-two. This ore, therefore, contains more iron per ton than either of the others. It tends to crystallize in black octahedrons, or eight-sided forms like Fig. 22, which are sometimes found scattered through crystalline rocks. Magnetite is so named because it strongly attracts the magnetic needle. Occasional pieces possess, also, the polarity of the magnetic needle, and these are known as *loadstone* or *lodestone*. There are several other ores of iron of less importance than these.

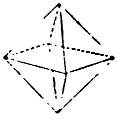


FIG. 22. OCTAHEDRAL CRYSTAL OF MAGNETITE.

We ought to make mention of a few additional minerals which sometimes give a qualifying character to rocks, even if they are not *constitutive*, like the others named. ***Pyrite*** or *pyrites* is bronze yellow, hard as quartz, and occurs in cubes and octahedrons. It is composed of sulphur and iron. ***Epidote*** is mostly a pale yellowish-green mineral, as hard as quartz, composed of silica, alumina, lime, and iron. It is known principally in a massive or rock condition, as a constituent of crystalline rocks. The crystals are generally elongated, sometimes needle-shaped or fibrous. *Garnet* is a generic name of minerals consisting of silica and various bases. The garnets present a great range of colors, but the common garnet is a deep wine-red. It is an iron-alumina garnet; when transparent, "precious garnet." It is easily recognized by its twelve-sided or twenty four-sided form. *Emery* is an impure corundum. The latter exceeds quartz in hardness, and consists almost wholly of alumina. All these minerals may be found in common bowlders, and the student must not cease to search until he finds them.

EXERCISES.

What is the nature of the rusty deposit from some spring waters? What is the nature of the white deposit? Suppose hæmatite combines with water, what does it become? If limonite loses its water, what does it become? How many pounds of iron in 2,000 pounds of limonite? How many in 2,000 pounds of hæmatite? How many in 2,000 pounds of magnetite? How many pounds of lime in 2,000 pounds of calcite? What use has calcite in agriculture? Which is most suitable to the soil, calcite or quicklime? What is the difference between farm plaster and plaster of Paris? If a supposed calcite does not effervesce with cold acid, what may be concluded as to its composition? How may calcite be easily distinguished from gypsum? Name all the white minerals thus far described. Which is hardest? Which softest? Which next to hardest? Show a specimen of calcite. Show some other minerals and name them. How can you distinguish mica from micaceous hæmatite? In a mass of iron ore kept constantly wet, which will we have, hæmatite, limonite, or magnetite? State where you have seen any of these ores. Which ore was it? How do you know? What are the uses of emery? What is an emery wheel? Have you found calcite in a rock abounding in quartz? If so, was the calcite generally distributed or in a layer? Was it fine-grained calcite or coarsely crystalline? Have you found calcite in company with biotite? In what sort of rock did you find octahedrons of magnetite? Show three specimens giving the three streaks of the principal iron ores. Why is hornblende darker than calcite? Why is it heavier than calcite? What minerals have you now in your collection?

STUDY VIII.—*Review of the Important Minerals.*

Of the thirty-five or forty species of minerals briefly noticed, the following are the most important in the study of rocks: Quartz, orthoclase, plagioclase, muscovite, biotite, hydromica, talc, hornblende, augite, calcite, and dolomite. The student who can discriminate these under their various aspects, and especially in rocks not coarse-grained, has accomplished much. The remaining species, nevertheless, are liable to be met, and many of them constitute important ingredients in certain rocks not generally distributed. This will appear when we come to the study of rocks.

We have prepared, for the convenience of the student, a tabular exhibit of the chemical composition of these minerals, and have added in the last column figures expressive of the hardness of each. The meaning of these figures is understood by reference to certain standards of hardness as indicated on page 42.

A few species are mentioned in the table for the first time.

TABLE OF COMPOSITION OF

		MINERALS.	OXYGEN.	SILICA.		ALUMINA.	OXIDES OF IRON.	POTASH.	SODA.
		Binary Compounds.							
		Quartz	53.33	......		......	......	......	......
		Hæmatite	30	......		......	......	......	......
		Limonite	25	......		......	......	......	......
		Magnetite	27.6	......		......	......	......	......
		Menaccanite	......	......		......	......	......	......
		Franklinite	......	......		......	......	......	......
		Pyrite	......	......		......	......	......	......
		Halite ("salt")	......	......		......	......	......	......
		Silicates.							
Feldspar.		Orthoclase	......	65	Acidic.	18	......	17	......
	Plagioclase.	Albite	......	68		20	......	......	12
		Oligoclase	......	62		24	......	......	9
		Labradorite	......	53	Basic.	30	......	......	4
		Anorthite	......	43		37	......	......	......
		Kaolinite	......	46.5		34.4	......	......	......
Mica.		Muscovite	......	47		33	3	10	2
		Biotite	......	36		16	20	8	......
		Phlogopite	......	40		15	5	7	3
		Lepidolite	......	48		25	9	9	......
		Hydromica	......	......		......	......	......	......
		Talc	......	63		......	......	......	......
		Pyrophyllite	......	65		28	......	......	......
		Serpentine	......	44		......	3	......	......
Chlorite.		Ripidolite	..	31		17	4	......	......
		Prochlorite	......	27		19	26	......	......
Amphibole.		Hornblende	......	50		10	8	......	2
		Tremolite	......	59		......	2	......	......
		Actinolite	......	57		......	5	......	......
Pyroxene.		Augite	......	48		7		......	......
		Sahlite	......	54		......	6	......	......
		Diallage	......	52		2	9	......	......
		Hypersthene	......	52		3	22	......	......
		Tourmaline (black)	......	37		35	12	......	2
		Epidote	......	38		22	13	......	..
		Garnet	......	35		7	28	......	......
		Carbonates.	CARBONIC ACID.						
		Calcite	44	......		......	......	......	......
		Dolomite	47.83	......		......	......	......	......
		Magnesite	52.4	......		......	......	......	......
		Siderite	37.9	......		......	62.1	......	......
		Sulphate.							
		Gypsum	......	......		......	......	......	......

THE COMMON MINERALS.

Magnesia.	Iron.	Water.	Other Constituents.	Hardness.
... .	.. ...	......	Silicon 46.67	7
......	70	. ..	....	5.5-6
......	60	15	....	5-5.5
......	72.4	......	Protox. Iron 31.03 + Sesquiox. Iron 68.97. Often with Titanium	5.5-6.5
......	. ....	......	Approximately, Perox. and Protox. Iron 54 + Oxide Titanium 43	5-6
.....	......	......	Hæmatite 66 + Sesquiox. Mangan. 14 + Protox. Zinc 20	5.5-6.5
......	46.5	......	Sulphur 53....	6-6.5
. ..	......	......	Sodium 39.3 + chlorine 60.7	2.5
......	**Lime.**	......	....	5-7
......	.. ...	... ..	....	6-7
......	5	......	....	6-7
......	13	......	....	6
......	20	.. ...	....	6-7
....	......	24.1	. ...	1-2.5
1	.....	......	Most actual examples 1-5 p.c. water, by alteration..................	2-2.5
17	......	......	....	2.5-3
28	......	......	... .	2.5-3
......	......	.....	Lithia 4 + Fluorine 5	2.5-4
......	......	5-10	....	1-2
32	......	5	.. ..	1-2
1	. ..	5	....	1-2
43	... ..	12	....	2.5-4
33	......	13	....	2-2.5
16	......	11	The Iron is a Protoxide	1-2
15	12	......	Iron is mostly Protoxide, and ranges to 20 p.c...	5-6
25	13	......	The Iron is a Protoxide..............	5-6.5
13.4	20	......	The Iron is a Protoxide	5-6
15	21	......	. ...	
15	23	. ..	....	
16	19	.. ..	....	
22	2	......	....	5-6
2	......	. ...	Fluorine 2 + Boron 8	7-7 5
......	22	2	Manganese oxide 0-5	6-7
......	28	......	This is the common Lime-Iron Garnet	6.5-7.5
..	56	......	....	2.5-3.5
21.73	29.44	......	Carbonate Lime 54.35 + Carb. Magnesia 45.65........	3.5-4
47.6	......	......	.. . .	3 5-4.5
......	.. ...	... ..	....	3.5-4.5
......	32.6	20.9	Sulphuric Acid 46.5	1.5-2

SCALE OF HARDNESS.

1.	Talc,	Scratched with the finger nail.
2.	Gypsum,	
3.	Calcite,	Easily cut with a knife.
4.	Fluorite (Fluor Spar),	
5.	Apatite,	Cut with difficulty.
6.	Orthoclase,	Barely scratched by steel.
7.	Quartz,	Not scratched by steel.
8.	Topaz or Beryl,	
9.	Corundum,	
10.	Diamond,	

The "Table for Determinations" must not be regarded as an infallible guide, but it will probably be an aid to the student. A great deal of exercise should be had on it.

TABLE FOR DETERMINATION OF MINERALS.

- Hardness 6.5 to 7 or over.
  - Lustre vitreous.
    - Color black; sometimes brown, green, blue, pink or white; often in prisms with curved, striated or fluted sides, ***Tourmaline.***
    - Color yellowish-green, ***Epidote.***
    - Color deep red, crystalline form conspicuous, 12–24-sided, ***Garnet.***
    - Color whitish, dusky, reddish; transparent when pure; crystalline faces not shown on fracture.
      - No double refraction; crystal, a 6-sided prism, ***Quartz.***
      - Double refraction strong (when transparent); crystal octahedral or cubical, ***Andalusite.***
  - Lustre metallic; color brass yellow, ***Pyrite.***
- Hardness 4.5 to 6.
  - Streak brownish yellow; lustre silky; often stalactitic or botryoidal, ***Limonite.***
  - Streak red; often lamellar, columnar or granular, ***Hæmatite.***
  - Streak dark reddish-brown; acts slightly on the magnet. ***Franklinite.***
  - Streak submetallic; powder black to brownish red, ***Menaccanite.***
  - Streak black, lustre metallic; crystals often octahedral, ***Magnetite.***
  - Streak light.
    - Streak white; color mostly light, ranging through white, gray, red, brown and green; lustre pearly or vitreous-pearly; texture not fibrous (FELDSPAR).
      - With right-angled crystallization; no surface striations; colors mostly white, creamy and pale red, ***Orthoclase.***

No exact right angle; striations often present; colors bluish, grayish, greenish, dusky or white, sometimes glassy transparent, *Plagioclase.*

Streak pale greenish.

Color black or greenish black; texture often fibrous; having no prismatic right angle (AMPHIBOLE). *Hornblende.*

Color green, greenish or greenish-black; often white if fibrous.

Texture seldom fibrous; having a prismatic angle of nearly 90° (PYROXENE), *Augite.*

Texture of radiating, prismatic, greenish fibres, *Actinolite.*

Texture of fine, parallel, whitish fibres or blades, *Tremolite.*

Streak grayish or brownish-gray; color dark brownish-green, grayish-black, greenish-black; lustre sometimes a little metalloidal, *Hypersthene.*

Hardness from 3 to 4.

Effervescence with acids; color generally nearly white; sometimes transparent; lustre vitreous or vitreous pearly.

Effervescence with *cold* acid; faces not curved; often translucent or transparent; generally distinctly rhombohedral, *Calcite.*

Effervescence only with *hot* acid.

Lustre inclining to pearly; color often brownish; faces sometimes curved, *Dolomite.*

Lustre vitreous.

Color white, yellow, gray, brown, green, *Magnesite.*

Color ash-gray to brown or red, *Siderite.*

No effervescence with acids; lustre greasy, waxy or earthy; color greenish; occuring only massive, *Serpentine.*

Hardness below 3; no effervescence with acids.

Structure distinctly foliaceous.

Folia elastic when unweathered.

Colors from black to greenish; lustre splendent, *Biotite.*

Colors gray, brown, greenish, violet, yellowish, olive-green; often transparent, *Muscovite.*

Colors yellowish-brown to brownish, often with copper reflections, *Phlogopite.*

Colors grass-green to olive-green; transparent to translucent, *Ripidolite.*

Folia inelastic, greenish, reddish or black.

Color pink or pinkish, *Lepidolite.*

Color apple-green to whitish; folia flexible but inelastic; feel greasy, { *Talc.*
Pyrophyllite.

- Color deep green (CHLORITE).
  - Ranging from grass-green to olive-green; folia somewhat elastic; transparent to translucent, ***Ripidolite.***
  - Ranging from grass-green to blackish-green; translucent to opaque, ***Prochlorite.***
- Color black; folia flexible; feel greasy; streak black; lustre metallic, ***Graphite.***

Structure indistinctly foliaceous or compact; green or greenish; lustre earthy. ***Hydromica.***

Structure not foliaceous; sometimes lamellar.

- Color light; lustre vitreous or silky; crystals transparent, ***Gypsum.***
- Color black; blackens white paper; in granular masses, ***Graphite.***

STUDY IX. — *Quartzose Rocks.*

We return now to the field and resume our intercourse with the bowlders. We should be prepared to study them now as rock specimens. Any accessible rocks "in place" — bed rocks — will be quite as suitable, and should be especially studied; but taking our country at large, not one tenth of our students could depend on finding a supply of rock specimens without recourse to bowlders. These are almost everywhere throughout our northern states. On the prairies and in the southern states where bowlders do not abound, they should be obtained from some bowlder-covered region. They should be had in large supply. Regions abounding in bowlders are even better situated for *lithological* studies than other regions, since the number of species to be had on a square mile is much greater than would be supplied within an equal area by rocks in place.

You have noticed that all the rocks which thus far have been in our hands for mineral study have been hard and made up of grains which are either crystals or fragments of crystals. They are therefore known as crystalline rocks. On the contrary, the bed rocks in most portions of the country are not so hard and crystalline. They consist of limestones, sandstones and shales, having mostly a dull lustre, often containing *fossils;* and if the constituents are sufficiently coarse to be detected with the magnifier, they are seen to be rounded as if they had themselves, at some time, been rolled about like bowlders. Many limestones, however, are exceptions to this statement, some of them, and most marbles, being decidedly crystalline. You have remarked then two series of rocks, the *crystalline* and the *fragmental;* and you already know that nearly all our bowlders belong to the crystalline series. Of the crystalline rocks you have already noticed many sorts or species, and you will find them very much more diversified than the fragmental.

Probably the first bowlder which we attempt to study will be a *quartzite*—a rock composed wholly of quartz, or nearly so, and either massive or thick-bedded. Glancing over the field, you will probably notice many white or very light-colored bowlders. Inspect one of them closely. Test it for hardness. You make no scratch. Examine its structure. Can you trace the outlines of its constituent fragments or grains? If you can do this easily, the quartzite is *granular.* But if you find the constituent grains closely pressed together, so that they seem to have indented each other and blended together, the quartzite is *vitreous.* Sometimes it is so vitreous as to almost constitute something like a mass of opaque glass. On the other extreme, the grains are sometimes so little adherent that the rock crumbles, and is then a *friable* quartzite. All this you can easily demonstrate in the field. Otherwise, the different sorts of specimens can be collected and brought before the class, and placed in your hands.

There are several other varieties of quartzites. They may be fine or coarse. When they contain pebbles they are *quartzose conglomerates.* Some are composed chiefly of white porcelain-like quartz; others, of a more glassy quartz. Some have grains or pebbles of jasper—red jasper being quite common. These are *jaspery.* There may be present sparsely scattered crystalline fragments of mica, hornblende, talc, chlorite, or other minerals which give a qualified character to the quartzite. It is then *micaceous*, *hornblendic*, *talcose*, or *chloritic.* Quite often the peculiar straight, long, black crystals of tourmaline are seen. With a little patience you may collect twenty or more varieties of quartzite.

But we have also *fragmental* quartzose rocks. The common sandstone seen in the bluff or used in some of our buildings is composed merely or mostly of grains of quartz. But when you inspect the rock, the shining lustre of the quartzite is wanting, and the grains are not so closely compacted together. The sandstone, therefore, is more easily broken; and *friable* kinds are of more frequent occurrence. Moreover, you will notice in every sandstone the presence of foreign particles, sometimes of an earthy character and sometimes of other minerals not quartzose. Among fragmental quartzose rocks there are also *conglomerates* and *grits* and materials of various colors, making the general tint of the rock gray, bluish, reddish, purplish, or even nearly white. The character of the sandstone may also be qualified by the presence of foreign ingredients like mica, clay, calcite, iron-rust, bitumen, petroleum, or coaly matters. It is then *micaceous*, *argillaceous*, *calcareous*, *ferruginous*, *bituminous*, *petroliferous*, or *carbonaceous*.

Most of the quartzites show little evidence of stratification or arrangement in layers or "beds." Others are *thick-bedded*, and still others are *thin-bedded*, and present a finer and generally more homogeneous texture. These are *silicious schists*. By the addition of mica, hornblende, or other minerals, they become *schists* of other sorts, as we shall see. When the bedded quartzites contain argillaceous matter, and are extremely fine and uniform, they constitute *novaculite*. When they are reddened by an abundance of hæmatite, they form a *jasper schist*. The jaspery materials are generally arranged in ribbon-like bands alternating with materials more hæmatitic or more purely silicious. These bands are often so folded and contorted as to constitute a curious and instructive study.

The materials of quartzose rocks sometimes occur quite uncemented. Indeed, all beds of sand are such, and illustrate what is supposed to have been the remote condition of most quartzose rocks. How the sand, in the course of time, has become so consolidated is not fully understood. Among some fragmental rocks, however, we can detect some kind of cement. Oxide of iron sometimes serves as such cement, and this imparts a reddish or yellowish color to the rock. Carbonate of lime is a common cement, and in such cases can be detected with the naked eye or the lens as a whitish filling of the interstices. Its presence, also, is denoted by a slight effervescence with acids. Some sandstones are so highly calcareous that on breaking the rock sparry reflecting faces are visible running through it for short distances. These are faces of the rhombohedral form under which the carbonate of lime has crystallized.

Many of you have noticed, scattered over the fields, flattened rounded stones of dark reddish color and considerable weight, apparently containing iron, but also with more or less fine sand disseminated through them. As found in the soil, they are generally composed of concentric layers, one within the other. The outer layers are distinctly reddish, and not very hard, but there is generally a central nucleus which is grayish-black, compact, and hard. Quite often the outer, softer layers are detached from the inner mass; and this often takes place before the stone is broken. The nucleus can then be heard rattling within, when the stone is shaken. These stones are the subjects of much curiosity and conjecture among those ignorant of geology. They are often called "iron-stones," "kidney iron-stones," or when clayey, "clay iron-stones," and with a little more correctness, "iron nodules" or "iron concretions." Now, the chemist ascertains for us that they are composed chiefly of carbonate of iron, and are, therefore, impure *siderite*. Our own inspection reveals a concentric structure, showing that they are ferruginous *concretions*. That is, the iron matter began at first to collect around a centre in some sand or clay rock, then successive layers collected around the first ones, so that the whole concretion is composed of a succession of concentric layers. It may be supposed the carbonate of iron moved through the rock in a state of solution. Arriving at its place, the carbonate was precipitated. When, at some later time, the nodule was left on the surface, exposed to the air, the iron on the exposed exterior united with more oxygen and became a peroxide, causing the carbonic acid to escape. As far as this action penetrated, a rusty shell was formed. Deeper within, the original condition remained. This is the state of partial change in which we find it. Now, if we reason correctly, the process of oxidation is continuing, and in the course of time will penetrate to the centre. Also, as the oxidation has penetrated only a certain distance, our thoughts go back to the commencement of the process. It had a beginning, and that was *not very far back in time;* for if it were, the oxidation would have reached to the centre before our day. Now, if we could ascertain how many years have been required for the oxidation to penetrate one sixteenth of an inch, we could easily calculate how long since the work began, if we might assume that the progress of it has been uniform. That is, the calculation would show how long a time has elapsed since those geologic events took place which left the nodule exposed to the peroxidizing action.

The process of concretion is noticed in other kinds of minerals, as we shall see. In ferruginous sandstone quarries we can sometimes observe it going on. A freshly exposed surface of the formation may exhibit a rude concretionary structure extending across two or more strata, as represented in Fig. 23. As the concretionary lines cross the lines of stratification, they are more recent than they. The arrangement of the material must, therefore, have taken place *in the rock*. In certain sandstones some of the iron bands become extremely solid.

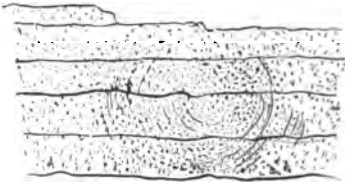


FIG. 23.—CONCRETIONARY STRUCTURE CROSSING SANDSTONE STRATA.

Quartzose rocks undergo less change than any others on exposure to the weather. They make, therefore, extremely durable *building* stones. Some of the sandstones, like the Ohio and Nova Scotia *freestones*, and the Connecticut valley "brown stones," are very highly esteemed. Even the flinty, quartzite bowlders, in regions where other good building stones are wanting, are sometimes broken up and dressed into shape for use with other dressed bowlders. Much sandstone is too incoherent for building purposes, and other sandstones after use develop rusty *stains*, through the peroxidation of the iron which they contain. The disintegration of friable sandstones has often resulted in extensive beds of sand, which are used, as well as the drift sand, in the preparation of *mortar*. When the sand is white and quite free from iron, it is employed in *glass making*. Grindstones and whetstones are made from fine and even-grained sandstones. Scythe stones are generally made from a fine-grained mica schist, of which we shall learn hereafter. Many hones are formed of fine homogeneous silicious schist. One well known sort comes from Nova Scotia; but the favorite hones are "Arkansas stones." Others are made from novaculite. These are some of the common uses of quartzose rocks.

EXERCISES.

Pick out from this collection of specimens all the quartzites. Select the vitreous quartzites. Separate the granular quartzites. Indicate those somewhat intermediate in structure. Point out a quartzose vein. How does a sandstone differ from a quartzite? Show a quartzite having two or more varieties of quartz. Point out a jaspery quartzite. One with tourmaline. One with mica scales. One with a little feldspar. Show a stratified quartzite. How does this differ from a sandstone? Exhibit a ferruginous sandstone. What is its color? What does that color result from? Show an argillaceous sandstone. Find some concretionary structure. What are the colors in it? What is the material? Why is one ferruginous sandstone yellow and another red? What change of color takes place when the yellow one is burned? What is the cause of the change? Why are quartzose rocks used for sharpening purposes? What is sand paper? What is emery paper? Which is most efficient, and why? What is a razor stone? Indicate some building in which sandstone is used. For what parts is it used? Whence was it obtained? State what defect is liable to appear in a sandstone used in building. Why do defects reveal themselves after the stone is built in, and not previously? What are flagstones? Mention a locality which affords good flagstones. What defects sometimes appear in flagstones after use? What is the cause of stains? Why do portions scale off? Why do flagstones sometimes break through the middle? Do the cracks generally run with the walk, or across the walk? What does this indicate? How are artificial flagstones made? What is a chalcedonic quartzite? A tourmalinic quartzite? Let two students have the task of collecting all possible varieties of quartzose rocks, collecting for some weeks, as opportunity offers.

STUDY X.—*Micaceous, Amphibolic, and Pyroxenic Rocks.*

I. Micaceous Rocks.

No bowlders are more abundant than those containing mica. On every hand its glistening scales may be seen reflecting the sunlight. It exists in all proportions from the scattered scales which characterize a micaceous sandstone or quartzite to such quantities as make it determinative of the character and name of the rock. When a quartzite contains as much as twenty-five per cent of mica, it forms the rock known as *greisen* (pronounced *gri'sen*).

We may return now to the same specimens used when studying dark-colored minerals. Here, besides the mica apparent in certain of them, we notice one or more light-colored sorts. Is either of them quartz? Test its hardness. Is either of them feldspar? Remember, you determine this, first, by hardness inferior to quartz, and superior to calcite; second, by its somewhat pearly instead of glassy lustre; and third, by its reflecting cleavage faces, which do not occur in quartz. If you are certain we have in this rock quartz, feldspar, and mica, each in considerable abundance, and no other mineral in much abundance, then the rock is *granite*, if it is massive or unstratified; but if it be thick-bedded, the rock is *gneiss* (pronounced *gnice*). If it is thin-bedded, with a large percentage of feldspar, it is also gneiss; but generally, when thin-bedded, the percentage of feldspar is rather small; the rock is composed chiefly of mica and quartz, and is called *mica schist*. In all these rocks the mica may be of any species, and so of the feldspar also.

The proportions of these constituents of granite and gneiss may vary to a great extent, and in this the general complexion of the rock may vary. We have very light granites and quite dark granites. Besides this, the colors of the quartz may vary, as well as those of the feldspar. If either the quartz or the feldspar is quite red and is abundant, while the mica is subordinate, then we have a decidedly reddish granite. The rock may also vary in fineness. Fine granites are most durable for building stones. Sometimes you find great crystals of feldspar or great flakes of mica, giving you the constituents of granite, but scarcely sufficiently mixed to form a proper granite.

Some recent lithologists do not separate granite from gneiss; and it is certainly difficult, sometimes, to decide from a hand specimen, whether the rock is stratified or not. We can only say that if the different minerals are equally distributed, the rock may be pronounced massive; but if the mica is ranged across the stone in bands, however indistinct, we may set the rock down as stratified. But these bands and the intervening feldspar or quartz must not be regarded as beds or strata. They are only laminæ. They may be of any thinness without making a thin-bedded rock. True beds are marked off by partings. The beds in a gneiss may be one, two, or eight feet thick, each marked by thin laminæ.

Now, here is a rock — a very common one, too — in which very little mica can be found. It is simply quartz and feldspar. We shall call this rock *granulite*, if it is massive, and *granulite gneiss* if it is thick-bedded. Some, not regarding mica a necessary constituent of gneiss, call this proper gneiss; and then as a difference of composition needs to be indicated some way, they call this "binary gneiss." We shall use terms uniformly as first explained. If the bedding becomes thin, the rock becomes a *granulite schist*. Then, if the feldspar fails, the rock is simply a quartzose schist. We study these granular quartz-feldspar rocks here, because they sometimes contain a little mica, and are always associated with micaceous rocks, and behave like them.

You will recall that altered product hydromica. This gives us a series of rocks parallel with that afforded by mica. Hence we have *hydromica granite*, *hydromica gneiss* and *hydromica schist*. Some hydromica schists are very fine-grained and homogeneous, having a bluish-gray color.

Any of these rocks are liable to contain accessory minerals.

Garnets very often occur in gneiss and mica schist. Other frequent minerals are tourmaline, epidote, chlorite, and andalusite.

II. Amphibolic and Pyroxenic Rocks.

The foregoing are the rocks resulting in case the dark mineral in our hands is mica. But taking another specimen, in which the dark mineral is *not* mica, we have to consider whether it is hornblende or augite. It is probably one or the other, if the mineral is constitutive — that is, sufficiently abundant to give character to the rock. Is the dark mineral hornblende? Well, if we have only quartz with the hornblende, the rock is a *hornblendic quartzite,* if massive or thick-bedded, and a *hornblende schist,* if thin-bedded — whether a little feldspar is added or not. But if the rock is almost wholly of hornblende, it is called *hornblende rock* or *amphibolite.* Sometimes such a rock is extremely fine-grained — cryptocrystalline — and it is then one of the varieties of *aphanite.*

If, however, we have quartz and feldspar with the hornblende, the rock is *syenite,* if massive — named from Syene in Egypt, where the same species of rock was quarried by the Egyptians centuries ago. As in the micaceous series, the rock, if thick-bedded, is gneissoid; but, as it has not the composition of simple gneiss, we will designate it *syenitic gneiss.* Similarly, if the rock is thin-bedded, we will call it *hornblende schist.* If, from syenite the quartz disappears, the rock becomes *hyposyenite* if the feldspar is orthoclase.

Many writers apply the name granite to syenite and hyposyenite; and some use the single term gneiss for these and the true gneiss. If, however, rocks are to be distinguished by their mineral composition, and terms are to be employed to express distinctions, there appears no good reason for suppressing the terms "syenite," "syenitic gneiss" and "granite," from the nomenclature of so-called metamorphic rocks, or those in which the crystallization is a secondary result, in distinction from eruptive rocks. We shall employ the terms uniformly as indicated above.

You must have remarked the great resemblance between granite and syenite, especially when the grains of the black mineral are very small; more especially if it is black mica which has begun to lose its lustre by absorption of water. In your visit to the stone-cutter, you found him calling them all "granite," but many reputed granites are more accurately syenites. "Scotch granite" is a syenite containing much red orthoclase. Most of the so-called granites, from Maine to Massachusetts, are syenites. The Quincy granite is a syenite. The capitol at Albany is chiefly syenite. In fact the great masses of crystalline granitoid rocks in the northwest, as well as New England, are chiefly syenites instead of granites. But good granites occur among our bowlders, and we shall certainly secure specimens. The "Obelisk," in New York, is a micaceous syenite rich in feldspar and with relatively large crystals of hornblende greatly subordinate to the mica. The Mormon Temple, at Salt Lake City, is the same but finer.

But what are these granite-like rocks which contain no quartz? We have handled many a specimen. Here is one composed of hornblende and orthoclase. Some call it simply "granite"; some "syenite"; some "quartzless syenite"; others, *hyposyenite*. We shall avoid confusion and promote convenience by using the latter name. But here is another rock in which the feldspar is striated — it is triclinic, or plagioclase. Hornblende and a plagioclase have generally been called *diorite*, if the rock is granite-like in texture. But we have to be a little more precise. There are several species of plagioclase. There is one group of them which is acidic, like albite and oligoclase, having a large percentage of silica (see Table); and another group which is basic, having less silica. Now we had better restrict the term diorite to mixtures of hornblende and an acidic plagioclase. Then mixtures of hornblende and a basic plagioclase, like labradorite and anorthite, will be called *norite* (called also *gabbro* by some, but this name is used in various senses). Some mica is often present in these two species of rocks; but the mica in diorite is generally light colored (muscovite), while that in norite is black (biotite). Some quartz, also, may be present in diorite, and then it is called *quartz diorite*. Accordingly, if we have a rock containing hornblende and a plagioclase we may consider the plagioclase acidic, if quartz or light mica is present; and basic, if no quartz is present, and especially if some black mica is present. In the former case the rock is diorite; in the latter, norite. Diorites and norites present all degrees of fineness; and when they are too fine for the constituent minerals to be seen with a magnifier, the texture is *microcrystalline* or *cryptocrystalline* — the latter term denoting a finer texture than the former. The rock is then a variety of *aphanite* — another variety being almost pure hornblende. Bedded aphanite is *aphanite schist*.

But suppose the dark mineral in a quartzless granite-like rock proves to be augite instead of hornblende. Now we may remember that augite, as a basic mineral, likes to associate with basic feldspars. Therefore in this case the feldspar is basic; that is, it is not orthoclase nor ,an acidic plagioclase; it is probably a basic plagioclase like labradorite and anorthite. Now augite and a basic plagioclase form *norite* and *diabase*. (For particulars, see Table, Study XIV.) Occasionally, however, we find augite with an acidic plagioclase, like oligoclase; but for this we have no different name; it is a section of diabase. But we do not find augite with acidic orthoclase. Remember then: If you have determined augite, the feldspar with it is a plagioclase and probably a basic plagioclase.

When any of the foregoing rocks present themselves in a thick-bedded condition, they are gneissoid; and for their description we may employ the terms *hyposyenite gneiss*, *diorite gneiss*, *norite gneiss*, and *diabase gneiss*. Similarly, any of these may also present a schistose structure; but it is not to be certainly concluded from this structure that such rocks have had a sedimentary origin, like common stratified rocks. That is still a question.

The rocks in the quartzless series are generally dark-colored; but not always. We may have a white plagioclase in great abundance, and but little hornblende or augite. The mixture of light and dark minerals results in a mottled or speckled, or "pepper-and-salt" appearance.

The rocks which we have been considering illustrate well the principles of mineral association. The companions of quartz are mica, orthoclase, and hornblende — not plagioclase (except albite) and augite. The companions of augite are the more basic plagioclases. Hornblende prefers biotite to muscovite; but not always. Thus biotite is found with basic plagioclase in norite, while the more acidic muscovite is found with the acidic plagioclase in diorite.

EXERCISE.

What is lacking in greisen to make it granite? What is lacking in granulite to make it granite? What would result from uniting greisen and granulite? What should we name an unstratified rock composed of quartz, feldspar, mica, and a little hornblende? What, if it is quartz, feldspar, and hornblende with a little mica? If we have quartz and feldspar together with a non-micaceous dark mineral, what, probably, is the latter? If we have quartz, muscovite, and a feldspar together, what, probably, is the feldspar? If we have quartz, hornblende, and a mica, what, probably, is the mica? If we have plagioclase and a mica, is the latter likely to be light or dark colored? Suppose the muscovite of a granite changes to hydromica, what does the rock become? If the pyroxene of a diabase changes to hornblende, what does the rock become? If the quartz disappears from syenite, what does the rock become? What change would convert hyposyenite to diorite? What would convert diorite to diabase? What would convert diabase to norite? What are the uses of syenite? Which is most durable, syenite or granite? Syenite or diorite? Coarse or fine granite? A basic or an acidic rock? Which weathers most rapidly, feldspar or quartz? Name several different varieties of granite. What does feldspar become on decomposing?

SUGGESTION.—The varying composition of the granular rocks thus far studied furnishes an interesting opportunity for a geological game. Prepare a quantity of cubical blocks of hard wood, half an inch or so in diameter. To a number of these attach tickets bearing the name of Quartz. To others attach tickets bearing the names of the other minerals occuring in the granular rocks. Then select two or three minerals (blocks), and lay them side by side, and see which one of a company can soonest tell what rock they represent. Let some umpire, with a supply of checks of any kind, supply the quickest correct respondent in each case with a check. When a given supply of, say, fifty checks is thus exhausted, let the number in each individual's possession be counted, and let the one having most checks be declared the winner of the game. On the same or future occasions other games may be played, and the first to win ten games may be declared entitled to a prize — whatever may be agreed upon and provided beforehand. In case of appeal from the decision of the umpire, reference may be made to one of the tables beyond. This suggestion relates thus far to massive granular rocks. But when it becomes desirable to make the game a little more difficult, the respondent may be required to state also what the rock would be if thick-bedded, and what if thin-bedded. The following minerals are suggested to begin with: quartz, orthoclase, acidic plagioclase, basic plagioclase, muscovite, biotite, hornblende, augite, talc, chlorite.

STUDY XI. — *Felsitic, Hydrous-Magnesian, and Aluminous Rocks.*

I. Felsitic Rocks.

We have picked up from time to time various round, smooth, and exceedingly fine-grained bowlders, to which we ought now to direct our attention. While the rocks which we have heretofore studied are sufficiently coarse-grained to enable us to inspect their mineral constituents with the naked eye, or at least with a pocket lens, these are too fine for that method of study. The former are *phanerocrystalline*; these are *microcrystalline* or *cryptocrystalline*, and their texture can only be seen under a compound microscope by the use of thin, transparent sections. Their composition may also be learned through chemical analyses. But we do not propose to resort to either of these methods. We must simply see what can be done without them.

We can at least distinguish colors. Let us separate the black and greenish-black specimens from those of other colors. These are chiefly *aphanites*; and we have studied them in connection with other rocks. Some of them can be slightly scratched, while others are as hard as orthoclase. The former are composed chiefly of hornblende, and might be styled *aphanitic amphibolite*, or *amphibolic aphanite*. These which are so flinty in hardness evidently contain quartz in intimate union with a dark mineral. The principal dark minerals are hornblende, augite, and labradorite. But quartz and labradorite have little to do with each other; and of the other two, quartz prefers hornblende. We may presume, therefore, that this flinty aphanite contains quartz and hornblende. But as quartz and hornblende do not much associate, except in company of an acidic feldspar, we may further conclude that the real mineral constituents of this aphanite are either hornblende, quartz, and orthoclase, or hornblende, quartz, and albite or oligoclase. Now, the former triplet gives us *syenitic aphanite*, and the latter, *dioritic aphanite*. This reasoning is validated by the other modes of study.

Now let us take up the microcrystalline specimens which present whitish, grayish, and reddish colors. Give attention, first, to those of nearly uniform color. We shall be able to conclude, after carefully testing the different specimens, that they differ slightly in hardness, like the aphanites. If we can make a discrimination of this kind, let us take, first, the hardest. Now, these are as hard as quartz, and there is no mineral but quartz which is likely to be abundant enough to supply these rocks. But these are not pure quartz; they have not the glassy lustre of quartz. They do, indeed, suggest the jaspers, but there is another alternative: they may contain feldspar, intimately mixed with the quartz. But, as before, it must be an acidic feldspar — probably orthoclase. Now, other examinations corroborate this induction. This is, then, simply a flinty, amorphous feldspar. It has received the name *petrosilex*, sometimes also known as *hälleflinta*, or false flint (Swedish, pronounced nearly *hellefiinta*).

Taking, next, the reddish or whitish specimen, we find that it has the hardness and lustre of feldspar, though it shows no cleavage faces. We can do no more. It seems to be a compact, amorphous feldspar. Other investigations show it to be chiefly a plagioclase. It is called *felsite*. Petrosilex is also *felsitic*, and by some is not separated from felsite.

Let us now give attention to the specimens separated as not having homogeneous colors. Our notice is at once attracted by the fact that they consist of a fine, homogeneous base or matrix, in which other minerals are imbedded. By testing for hardness, as before, we find that this base by itself is sometimes a felsite, and sometimes a petrosilex. Without regard to this distinction, let us study the imbedded minerals. In one specimen they are clearly crystals of feldspar. Now, crystals of any kind, imbedded in a homogeneous feldspathic matrix, form a *porphyritic* rock. This is, then, a *porphyritic felsite*, and this porphyritic rock is the typical *porphyry*. Notice the colors — reddish or grayish base, with white crystals imbedded.

If we find imbedded crystals or fragments of quartz, the rock is a *quartz porphyry;* and if we find rounded pebbles thus imbedded, the rock is a *conglomerate porphyry*. This unusual variety of porphyry we shall probably not meet with. It forms, however, the porphyry point at Marblehead, Massachusetts. Other porphyries may be seen at Lynn and Nahant, and they are very common around the shores of Lake Superior. (See Fig. 8.) Other kinds of rocks, also, besides felsites, are often found porphyritic. Figure 24 shows a porphyritic granite.

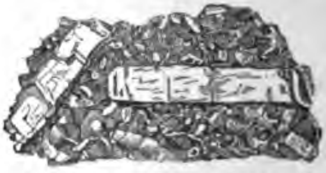


FIG. 24.—PORPHYRITIC GRANITE, from Land's End, England.

II. Hydrous-Magnesian Rocks.

Let us now direct attention to the Hydrous-Magnesian Rocks. These, as will be inferred, are characterized by the presence of the hydrous-magnesian minerals. If you turn to the table of composition of minerals, on page 40, you will perceive that all these minerals range low in respect to hardness. They must, therefore, impart a moderate hardness to the rocks. You will notice further that they are less rich in iron than the dark-colored minerals. Hence the rocks which they form will be of light colors and of low specific gravity. Now, in consequence of this comparative softness, we cannot expect bowlders of these rocks to have lasted through the wear and tear of geologic time, like the bowlders of harder rocks. For these reasons the student may have to depend partly on descriptions. Still, there are some of this class which, from the quartz contained, have lasted to our time. One of these, *protogine*, consisting of quartz, feldspar and talc, in a massive state, is not often met in this country ; but it forms the central mass of the high Alps of central Europe, and rounded masses are often seen borne to the lower levels by glaciers. Protogine occurs sparingly in the northwestern states. In bedded conditions it gives us *protogine gneiss* and *protogine schist*. The last is not essentially different from *talcose schist*. The latter, however, as we actually find it, consists almost wholly of minute folia of talc. It is a rare rock, though occurring near Marquette, Mich., at various localities in northern New York, and in other regions. But it must no longer be confounded with the *sericite schist*, or hydromica schist, which was till recently mistaken for talc schist.

Every one is acquainted with the so-called " soapstone " griddles, and the slabs of "soapstone" used for foot-warmers — their power of retaining heat being very great. This soapstone is the *steatite* of the geologist, and consists essentially of grayish, compact, amorphous talc. It is soapy to the feel, and is easily cut with a knife. When quite pure it is milk white, and forms the article known as "French chalk." The uses of steatite are quite numerous. Slabs of it are employed for fire stones in furnaces and in stoves. The fine-grained varieties are carved into ornaments. Inkstands are often made from it, especially the white variety. Ground steatite is employed for diminishing friction, and the manufacture of porcelain and the removal of oil stains furnish other uses. The so-called "soapstone" of the artesian well-borer is merely an unctuous, partially indurated clay.

Next, there are the chloritic rocks. *Chlorite schist* occurs in the mining regions of Lake Superior. It is a dark-greenish, greasy looking rock, in which chlorite, in closely aggregated or interwoven folia, is the chief, sometimes nearly the sole, constituent, while quartz is generally the principal ground mass. The feldspars, however, enter into this schist in about the same proportions as in mica and hornblende schists. By increase of the feldspar, accompanied by a heavier bedding, this schist graduates into *chloritic gneiss*. In the opposite direction it graduates into *chlorite slate*, a fine slaty rock, containing some aluminous matter. A rock composed mostly of chlorite is called, also, *chlorite rock*.

III. Aluminous Rocks.

Passing to aluminous rocks, we have first the fine white slate, composed of pyrophyllite, and having the softness, appearance and soapy feel of the talcose rocks, and known as *pyrophyllite slate*. It occurs in place in North Carolina, and one of the varieties is employed in making slate-pencils. But the greater number of aluminous rocks are characterized by a *clayey* constituent, the basis of which is kaolinite. When the material is unconsolidated and comparatively pure, it forms kaolin, extensively used in porcelain making. When mixed with various impurities, and more or less silica, it constitutes common clay. This is sometimes dark, or even black, from the abundance of carbonaceous matter. It is sometimes reddish, bluish or whitish, depending on purity and the nature of the impurities. The burning of clay not only hardens it, but generally imparts a reddish color, through the peroxidation of the iron. If, however, the iron exists as a silicate, no reddening takes place. This is the character of the "Milwaukee brick," so-called; though this sort of clay is extensively distributed throughout the lake region. *Fire clay* is a clay free from iron, lime or other substance which would promote fusion; and is therefore capable of resisting intense heat. It generally contains much arenaceous matter, which prevents shrinkage and warping of the fire-brick.

When clay with more or less arenaceous or silicious matter has become somewhat indurated, it assumes the character of a *shale*, a rock which easily splits into somewhat even flakes, and presents many varieties in composition and color. Perhaps the most accessible examples are the dark shale fragments often found mixed with our supply of coal. Most shales are dark, and many are even black, from the abundance of carbonaceous matter contained in them. The carbon, under such conditions, possesses a strong predisposition to unite with hydrogen and pass into bitumen.

When, finally, the clayey rock has been firmly hardened, it constitutes *argillite* or *clay slate*, called sometimes *phyllite*. In color it is bluish, whitish, reddish or greenish. It splits into thin, even layers, and is extensively employed for roofing and for writing slates. Argillites are almost microcrystalline; but in some cases we find them graduating into a very fine mica schist or hydromica schist; and in others, by a large accession of extremely fine arenaceous matter, they become *novaculite* or "oil-stone."

EXERCISES.

How does petrosilex differ in composition from felsite proper? How does it differ from aphanite? What is the difference between a porphyritic granitic and a granitic porphyry? Which is most basic, felsite proper or petrosilex? What is the difference between kaolin and felsite? What is the effect of intense heat upon clay? What is the effect on kaolin? Give an example of burned kaolin. Is it opaque or translucent? How might it have been made more translucent? What is the difference between porcelain and felsite? Which contains most alkali, kaolin or orthoclase? What causes burnt clay sometimes to be vitrified? What kind of clay would not vitrify? What are unvitrifiable clays used for? What is the effect of limestone pebbles in brick clay? What causes some bricks to "slack"? What causes the dark color of aphanite? What causes its hardness? If the hornblende should be removed from dioritic aphanite what would it become? What is the difference between pyrophyllite slate and talcose slate? Between talcose slate and steatite? Between protogine and granite? Between syenite and augite-syenite? What class of crystalline rocks is not likely to be found as bowlders? Why not? Why are bowlders predominantly quartzose? Mention four or more different rocks or minerals used for making colored marks. What change must be made to convert norite into diabase?

STUDY XII.—*Calcareous Rocks.*

Let us get together samples of the common rocks which effervesce on the application of acid, with or without heat. They are composed essentially of calcite and dolomite. We obtain them at the stone cutter's, from broken articles in marble, from among certain building materials, and occasionally among surface bowlders. If any limestone or marble ledges exist in the vicinity, we shall, of course, obtain specimens from the rocks in place.

With our assortment before us, we notice at once that some of the specimens are brighter and more lustrous, others are duller and more earthy. The former are cystalline, the latter uncrystalline. The former are purer, the latter have admixtures of various accessory ingredients. The former we call *marbles;* the latter, *limestones.* The marbles are thick-bedded and have hardness and homogeneity, and freedom from cracks and cavities. They can be cut and polished. The limestones are thick- or thin-bedded; but they are not homogeneous, and generally contain fissures and cavities. They cannot be advantageously cut into slabs and polished. Some limestones, however, without being crystalline, are sufficiently thick-bedded and homogeneous to be sawed and polished; and when they contain many fossil shells, encrinites or corals, the polished surfaces are handsome. Such marbles are known as shell marble.

Of the crystalline, heavy-bedded marbles we have endless varieties of color and texture. The granular, white sorts are called *saccharoidal.* Fine white, even-grained sorts are *statuary marble,* of which the most celebrated quarries are the Parian and Pentelican, in Greece, and those of Carrara, in Italy. By the dissemination of streaks of aluminous matter, *clouded marbles* are produced, which are common in Vermont. An abundance of bituminous matter makes a black or *Egyptian marble* which also occurs in Vermont. It may be varied with lighter matter. Some good marbles are calcareous conglomerates. A much admired sort is quarried in eastern Tennessee, and is used for pillars in public buildings. *Verd antique* marble is a dark green serpentine clouded and varied with lighter calcite.

Of the uncrystalline, lustreless limestones we find also endless varieties. They are caused chiefly by the variations in the impurities. Sometimes an inspection of a freshly broken surface shows a sparry constitution, somewhat approaching that of a marble. Very frequently limestones are more or less saturated with *petroleum*, which gives them a brown or very dark color. Black limestones contain carbonaceous matter. Bluish and ashen limestones are *argillaceous*. Yellowish and reddish limestones are *ferruginous*. Sometimes grains of sand are disseminated through a limestone, which is then *arenaceous*. If silicious matter not in an arenaceous state is intimately mixed or combined with the calcareous, the limestone is *silicious*. If alûmina is so combined the limestone is *aluminous*. Distinguish particularly argillaceous and arenaceous from aluminous and silicious. The first two terms imply the material in a somewhat isolated and visible state; the other two imply it intimately commingled, or perhaps chemically combined.

Many limestones are magnesian. They do not effervesce freely. Let us pick out such from our collection. They do not look very different from the others. Most of the great western limestone formations, so called, are magnesian, or even dolomitic —that is, about one-half carbonate of magnesia (see the Table of Compositions, page 40). Though dolomites are not properly separable by their color, it happens, as a fact, that most of the western dolomites present a buffish hue. This is especially the case with the "lower magnesian limestone" which helps to form the cliffs along the Upper Mississippi. The observation may also be made in Missouri and Michigan. As a fact, it is further observable that many dolomites and dolomitic limestones have a finely granular texture. In fact, they have been sometimes reported as sandstones. So the buff color and granular texture may be taken as a preliminary indication of a dolomitic formation. Slowness of effervescence is confirmatory. Beyond this we cannot go without chemical analysis.

You have, perhaps, noticed some limestone containing small, spherical pellets, like homœopathic pills. Such limestone is *oölitic* (not pronounced oo-litic). Such pellets sometimes compose the entire rock, which is then an *oölite*. Examination of these spherules broken through the middle reveals a concentric structure. It is then a "concretion," similar to the concretionary "iron-stone" before mentioned. When the concretions are larger the rock is *pisolitic.*

Limestones have no standard degree of hardness. All may be easily scratched; but in the Gulf States are limestones which may be cut with the knife. One of these is the widely known "rotten limestone"; another is the so called "white limestone." But they are harder than chalk, and, besides, have "grit" disseminated through them. Some *chalk* is pretty free from grit, though it abounds in nodules of flint. It does not occur in America, but comes chiefly from England and France. "Whiting" and "Spanish white" are prepared from it. *Marl* may be described as unconsolidated chalk. We have already learned (in Study II — but see especially Study XV), how it is deposited. We have learned, also, of the origin of *travertin* and *tufa.* When calcareous waters drip from the roof of a cavern, the deposit formed on the floor is *stalagmite;* and the icicle-like form pendant from the roof is a *stalactite.* The banded colorations in stalagmite fit it for many ornamental uses.

All calcareous rocks are slightly soluble in meteoric (or atmospheric) waters; hence, when used in architecture or art, in exposed situations, they possess a limited durability. The slow decay of limestones and marbles may be noticed in some of our oldest structures. Marble cemetery slabs or monuments, one or two hundred years old, are distinctly weathered. On the dome of St. Paul's Cathedral, London, the weathered, earthy limestone has retreated a quarter of an inch, leaving the silicified fossils projecting to that extent. Yet many of the ancient statues and columns buried in the earth have retained admirable perfection. In the ruined but famous Palace of the Cæsars, at Rome, the architectural carvings retain striking sharpness and distinctness, after two thousand years of exposure. On the other hand, most of the caverns of the world are attestations of the solubility of limestone. They began as fissures, through which streams of water passed, dissolving continually — and also wearing — the limestone surfaces. That such works have been long in progress is evidenced by the slow yielding of calcareous surfaces during historic times.

Limestones, considered in reference to their fitness for building, should be examined as to their power of absorbing and retaining water. A saturated limestone subjected to freezing is liable to crumble, or even to be completely shattered. Hence, argillaceous and aluminous limestones are quite unsuitable for situations exposed to the weather. Some of the latter, presenting a fine-grained, massive, and substantial appearance when issuing from the quarry, may be reduced to a state of ruin by the frosts of a single winter.

A *hydraulic limestone* is one which contains a considerable percentage (fifteen to thirty per cent) of clay or magnesia, or both together. Calcination renders the silica of the clay soluble at the same time that the carbonic acid is expelled from the carbonate of lime. Contact with water, therefore, dissolves the silica, and this, with the quicklime, slowly forms a hydrous silicate of lime, which is firm and insoluble. Another portion of the silica forms a silicate of alumina; and if magnesia be present, a silicate of magnesia also results.

Gypsum is a calcareous rock of much importance, having most of the properties of the mineral gypsum, already studied. We find it mixed in all proportions with argillaceous matter, and sometimes disseminated richly through argillaceous limestones. It also occurs in stratified beds of great or small extent. Sometimes the original bed has been dissolved away, and only some lenticular remnants of it are found. Often, also, the disappearance of a gypsum bed occasions "sink holes" at the surface. Such holes, then, seem to indicate the presence of an underlying soluble stratum, probably gypsum. But they must be carefully distinguished from mere depressions in the drift, sometimes called "potash kettles." Much of the gypsum found in the crude condition contains a considerable admixture of clay, and possesses a bluish color. In other situations — as at Grand Rapids and Alabaster, Mich. — beds of gypsum exist in a state of great puritv, and then it exhibits a crystalline texture. White, granular deposits afford *snowy gypsum.* Gypsum equally fine and uniform is often tinted with rich colors. Fine gypsum, capable of forming ornaments, is known as *alabaster.* It may be white or colored. Near Grand Rapids, in Michigan, are extensive beds of pure gypsum, having largely a coarse fibrous structure. Some portions, however, are granular. This formation seems to extend under the central part of the state, for it reappears on Saginaw Bay, where it is also extensively quarried. Other sources of commercial gypsum are on the border of Sandusky Bay, Ohio, and in central-western New York. It is abundant, also, in Virginia, Tennessee and Arkansas. Very fine and extensive deposits exist in Nova Scotia. Gypsum is widely employed as an agricultural fertilizer, also as a plaster for "hard finish," and also in the preparation of "moulds" and "casts."

EXERCISES.

What change does calcined gypsum undergo when long exposed to the air? What change does quicklime undergo when so exposed? Which is most impaired by mere dampness? How does dampness affect water-lime? Why might not water-limestone calcined at a white heat make a good cement? Explain how a water-lime might be prepared from pure caustic lime. Would caustic lime and pure sand make a cement? Why do you give this answer? Would caustic lime and clay make a cement? Why this answer? How is silica made soluble? What is the use of insoluble silica in a cement? Which most rapidly dissolves, gypsum or limestone? Why did the "Cardiff giant," made of gypsum, possess an ancient appearance after a few months' burial? What is the source of rust stains on the surface of some marbles? Have you any specimens from any cavern? Describe them. How might human bones become buried in stalagmite? Have you ever heard of such a case? Have you ever heard of bones buried in travertin? Mention some extensive deposits of travertin. How does travertin differ from common limestone? How would slabs of alabaster serve as an external veneering for house fronts? By what means may plaster casts be rendered harder than results from the simple "setting" of the plaster?

STUDY XIII.—*Carbonaceous and Iron Ore Rocks.*

I. Carbonaceous Rocks.

Coal is something so familiar that a brief study will make us acquainted with its physical characters and modes of occurrence. Its geological history must, of course, be taken up in another connection. You have seen the "soft coal" burning on the grate, and have noticed the escape of inflammable and other gases; and have also detected the peculiar empyreumatic odor which bituminous coal emits. You have seen the gas-making coal put in the retorts at the gas works, and thus received other evidence that common coal contains some constituents which may be driven off by heat. Now, what are these volatile constituents, and what is the coal? Manifestly they are both combustible. The gas burns at the jet, and the coal and gas together burn on the grate. Even the coke which remains in the retort after the gas is disengaged is also combustible. Now, what is that which is combustible in common air, and is also an abundant substance? It is carbon; and this element, therefore, is the basis of all the coals and the inflammable gases derived from coals.

If we call the chemist to our aid, he informs us that the gases are compounds of hydrogen and carbon; and so are the coals, but with a diminished proportion of hydrogen, and the addition of oxygen. He informs us, also, that coal tar and other liquids derivable from coal, such as naphtha and coal oil, are other compounds of carbon and hydrogen. We observe, also, that the coals called *anthracite* contain comparatively little of the gaseous and fluid hydrocarbons, while those called *bituminous* contain larger percentages—the fixed constituents of both classes of coals being essentially carbon, or something not very different from charcoal.

A coal from which all volatile constituents have been expelled is *graphite* or *plumbago;* while on the other hand, we find in nature products composed of the liquid constituents occurring in coal, and others composed of the gaseous constituents. The liquid product is *petroleum*, and the other is natural *inflammable gas*. The petroleum has accumulated in reservoirs in the rocks to an extent which becomes a great natural curiosity — some wells having discharged five thousand gallons a day; and the gas is now escaping through artesian borings in such enormous supply as to light cities and furnish fuel for great manufacturing operations. Pittsburgh and its vicinity are especially favored with combustible gas; though enormous outflows exist in Knox county, Ohio, and in various other regions. Though petroleum and gas may be artificially produced from bituminous coal, it must not be inferred that these natural products have been so derived; since according to the evidences, no connection with coal beds usually exists. A striking proof of this has very recently been brought to light in northwestern Ohio, in a region at least eighty miles from the nearest coal field, where from three wells half a million cubic feet of inflammable gas are obtained daily from a geological position two thousand feet or more below the horizon of the lowest coal (Orton). Probably, however, like coal, petroleum and inflammable gases have had an *organic origin*. (See, further, Study XXIX.)

When petroleum is exposed to the air it loses its volatile constituents, and the fixed residuum is *asphalt*. Different varieties of asphaltic products have thus accumulated in deep rock fissures, and they are known by such names as *albertite*, *grahamite*, and others. *Succinite*, or the essential part of *amber*, is an oxygenated hydrocarbon, which may be mentioned in this connection. It is believed to be a fossil resin.

Peat you may find accumulating around the borders of lakes and ponds. (See Fig. 25.) Often the basins of old lakes are completely filled with peat. Manifestly it is of vegetable origin. It has a dark brown or nearly black color. It is combustible, and emits, like coal, an empyreumatic odor. Some old, deeply buried peats closely resemble that sort of coal known as *brown coal*, and *lignite*. These, like peat, have no standard purity. They may be worth more or less as fuel. Peat, however, is extensively employed on the continent of Europe in porcelain stoves for warming houses. If we arrange some of these carbonaceous and hydrocarbonaceous substances in serial order, they will stand somewhat as follows :

1. *Gases.* Like the light and heavy inflammable gases.
2. *Liquids.* Like Naphtha, Petroleum, Benzole, Tuluole, etc.
3. *Waxy Solids.* As the Paraffine and Scheererite groups of substances.
4. *Firm Solids.* (*a*) Asphaltic, like Asphalt, Albertite, Grahamite, Torbanite ; (*b*) Coaly—a series including Peat, Lignite, Bituminous Coals, Anthracite, Graphite, Diamond (?).

II. Iron Ore Rocks.

On visiting any iron ore mine we perceive that the ore occurs as a rock more or less distinctly stratified. We find the ore beds formed from the three principal ores already studied. They form strata like the other rocks with which they are associated. Generally, the stratification of the ore is quite conspicuous. Sometimes, however, the beds appear to wedge out in all directions, and thus to terminate. It is so with the beds at Lake Superior, in northern New York, in Missouri, and elsewhere. The ores in these beds are mere masses of *hæmatite schist*, or *magnetite schist*, and the kinds are distinguished in the same way as the minerals bearing these names. Great beds of *titanic iron ore* also exist in Canada and other regions, which seem to be substantially a mixture of magnetite and oxide of titanium. But titanic ores present various percentages of protoxide and peroxide of iron with binoxide of titanium. The *Franklinite* ores of New Jersey consist of hæmatite about two-thirds, and oxide of zinc one-fourth, the remainder being manganese. Sometimes these great iron-ore masses terminate abruptly against the "country rock" ; but often they disappear by gradual increase of other rock constituents. The accession of silica gives rise to a silicious ore ; then, at a remoter point, to a lean silicious ore ; then, to a highly ferruginous jaspery schist, as previously explained, and, finally, an ordinary silicious schist, or other rock. Mixed with clay, hæmatite forms *argillaceous hæmatite*, which is often of a deep red color, varying to brownish black. It has sometimes an oölitic structure.

Limonite rocks result from the hydration of the hæmatite and magnetite schists, and, in the regions just named, the process can sometimes be seen incomplete. Extensive beds exist in Salisbury and Kent, Conn., as also at sundry points in Dutchess county, N.Y. At Hinsdale, Mass., it occurs as the cement in a conglomerate quartz rock. The commencement of such a process of cementation of pebbles is often observed in the limonitic deposit from springs. These deposits, as explained in Study II, give rise to extensive beds of *bog iron ore*, or swamp limonite. One of the most desirable ores of iron is limonite, since, though less rich than hæmatite and magnetite, it is more easily reduced. The iron yielded by bog ore, however, is *cold short*, owing to the presence of phosphorus, and hence cannot be employed in the production of wire, or even of sheet iron. For casting it is superior.

Another important class of iron ores is afforded by siderite, or carbonate of iron. It is generally known as *spathic iron*. It occurs in gneiss, mica schist, and argillite, sometimes in extensive beds, as in Styria and Carinthia, and at Plymouth, in Vermont, Sterling, Mass., Antwerp and Rossie, N. Y., and the Fentress and Harlem rivers, N. C. Siderite is often found united with argillaceous matter in the form of nodules (kidney-iron) and beds (clay iron-stone), especially in the coal regions of the country, though this form of ore exists also in other formations.

III. Eruptive Rocks.

That such rocks as sandstones, limestones, and shale have had a sedimentary origin is apparent from the bedded arrangement of their materials in parallel layers; from the identity of those materials with the sediments gathering over modern sea bottoms, and from the presence in them of so many relics of the organisms of the sea — but of all this we shall learn hereafter. If traces of stratification are proofs of sedimentary origin, then many of the crystalline rocks are also sedimentary. All the schists and gneisses are stratified; and granite sometimes passes by continuity into gneissoid rocks. But lavas erupted from Vesuvius are not sedimentary. They may, indeed, acquire a parallel fibrous, or even bedded, structure by flow while in a molten state; and some geologists maintain that the bedded structure of gneisses and diorites and many other rocks had its origin in the flow of molten matter; but there are serious objections to this view. We have studied them without any theory as to their origin. We may admit that certain rocks which we have grouped with the sedimentary class are sometimes eruptive, or that certain ones have always an eruptive origin. If so, then we may have eruptive granites, syenites, diorites, norites, and diabases, as well as metamorphic ones of sedimentary origin; or we may regard some of them, like diabase, felsite, and the porphyries, as exclusively eruptive. In any event, we have to admit the existence of certain rocks which bear so much resemblance to modern lavas that we can regard them as nothing else than ancient lavas.

There are neither modern nor ancient lavas lying within accessible distance of us; and the ancient erupted rocks of Lake Superior and the Canadian regions have not endured the long journey to our doors, as common bowlders have. This simple fact gives one clew to their nature. They are more basic; they contain mostly less silica, at least they are not quartzitic; they have dissolved; they have been worn out. So much is certain. But again, we have learned from the other rocks what the chemical elements are, and what are their mineral compounds. The erupted rocks could contain few, if any, new minerals. But, having been molten, the same minerals must exist in a blended condition. Now, though it is impracticable to make a detailed study of the eruptive rocks, we may report that investigation confirms the deductions we have drawn. So we have chiefly a feldspathic series, a hornblendic series, and an augitic series. Beyond this it would hardly be profitable to go without other facilities than we propose to employ.

The following rocks, already noticed, are included also among erupted rocks: granite, granulite, felsite, syenite, quartz-syenite, diorite, quartz-diorite. The following are named only among eruptive rocks: 1. Feldspathic: phonolite, trachyte, rhyolite or glassy rocks, as pearlstone, pitchstone, obsidian, pumice. 2. Hornblendic and augitic: andesite, quartz-andesite (dacite), variolite, augite-andesite, dolerite (basalt), amphigenite (Vesuvian lava). On "volcanoes" and "ancient lavas" see Studies XXIII and XXIV.

EXERCISES.

What is the material of our so called lead pencils? What proportion of carbon is in them? How does graphite differ from anthracite? Is graphite combustible? What gem is pure carbon? What is its hardness? Name another carbonaceous substance with much lower hardness. How does peat differ from bituminous coal? From what is peat derived, according to your observation? What is paraffine? What are its uses? In what respect is amber like asphalt? Have you ever seen a magnetite schist? What is the color of the dust resulting from the handling of magnetite schist? What color of dust arises from hæmatite schist? What color of dust stains the wagons and cars carrying Salisbury (Conn.) iron ore? What color of dust stains the docks at Escanaba and Marquette, Mich.? What is "cold short" iron? What ore of iron most disturbs the magnetic needle? Name the rocks found in both the metamorphic and eruptive series. How can you determine to which series a particular granite belongs?

STUDY XIV.—*Retrospect of the Rocks.*

A retrospective glance over the rocks which are here studied recalls the fact that different rocks having the same constituent minerals differ chiefly in their structure. They may be crystalline or fragmental. They may be unstratified, or thick-bedded, or thin-bedded. They may be well consolidated, or imperfectly so, or quite unconsolidated. We notice that most of the rocks are characterized in part by some predominant mineral, such as quartz, mica, hornblende, pyroxene, and so on; and that we thus have several series, each of which runs through the various types of structure. A panoramic presentation of the common rocks, arranged according to structure in the several series, will aid greatly toward a comprehensive grasp of the subject. Such a presentation is attempted in the "Table of Rock Structure," which follows.

Again, we may make an arrangement of rocks according to the minerals which they contain, noting at the same time the variations of structure for the same mineral aggregates. This is attempted for the common rocks in the appended "Table of Rock Composition." In this, in each compartment, the "massive" rock stands first, and is put in small capitals; the thick-bedded rock next, in "Roman letters"; and the thin-bedded (to which we restrict the term schist) stands last, in "italics."

Finally, we introduce a "Table for Rock Determination," similar to our previous "Table for Mineral Determination." The intention of this is to enable the student to ascertain the name of a rock as soon as he knows its constituent minerals. This table, as we think, will be found extremely useful; and much exercise should be had on it. But we ought to remark that both the tables for determination contain much more detail than the student of the *elements* of geology can be expected to acquire. Accordingly, a star is prefixed to names of species regarded important for the elementary student. The further use of these tables is intended for more advanced study.

TABLE OF ROCK STRUCTURE.

		Quartzose Series.	Micaceous Series.	Amphibolic Series.	Pyroxenic Series.	Hydro-Magnesian Series.	Aluminous Series.	Calcareous Series.	Carbonaceous Series.
Crystalline.	Massive. (Granitoid.)	Quartzite.	Granite. Granulite.	Syenite. Hyposyenite. Diorite. Norite. Euphotide.	AugiteSyenite. Diabase.	Protogine. Steatite. Serpentine.	Granite Porphyry. Microcrystalline Felsite. Cryptocrystalline Felsite. Quartz Porphyry. Feldspar Porphyry		Graphite.
	Thick-Bedded. (Gneissic.)	Quartzite, Vitreous. Granular. Conglomeritic.	Gneiss. Granulite Gneiss	Syenite Gneiss. Diorite Gneiss. Norite Gneiss. Hyposyenite Gneiss Diorit. Aphanite. Hornblen. Aphanite	Diabase Gneiss Diab. Aphanite	Protogine Gneiss. Ophiolite.	Bedded Felsite. Bedded Petrosilex.	Marble, Saccharoidal. Statuary. Conglomeritic. Ophiolite.	Anthracite.
	Thin-Bedded. (Schists.)	Quartz Schist. Silicious Schist. Jasper Schist. Novaculite.	Mica Schist. Sericite Schist. Hydrom. Schist. Granulite Schist.	Amphib. [Schist]. Hornblende Schist. Actinolite Schist.	Augite Schist. Pyroxenite.	Protogine Schist. Talcose Schist. Chloritic Schist. Chlorite Slate.	Argillite. Pyrophyllite Schist	Marble.	Anthracite.
Uncrystalline.	Indurated.	Sandstone, Compact. Conglomerate	Mica. Sandstone.	Hornblendic Sandst			Slate.	Limestone, Compact. Shell Marble. Travertin. Calcareous Tufa.	Bituminous, Caking. Non-Caking. Cannel.
	Semi-indurated.	Sandstone, Friable.	Mica. Sandstone. Friable.	Hornblendic Sandst Friable.			Shale, Argillaceous. Bituminous.	Limestone, Soft. Chalk.	Brown Coal.
	Incoherent.	Sand.					Kaolin. Clay.	Marl.	Peat.

TABLE OF ROCK COMPOSITION.

	Quartz.	**Orthoclase.**	**Albite.**	**Oligoclase.**	**Mica.**	**Hornblende.**	**Talc.**
Quartz.	Quartzite. *Quartz Schist.* *Silicious Schist.* *Sandstone.*	*	*	*	*	*	*
Orthoclase.	GRANULITE. Granulitic Gneiss. *Granulitic Schist.*					*	
Albite.	ALBITIC GRANULITE *Granulitic Schist.*					*	
Oligoclase.	OLIGOCLASIC GRANULITE. *Granulitic Schist.*					*	
Mica.	GREISEN. Micaceous Quartzite. *Mica Schist.* *Micaceous Sandstone.*						
Hornblende.	Hornblendic Quartzite. *Hornblende Schist.*	HYPOSYENITE. Hyposyenitic Gneiss.	DIORITE. Dioritic Gneiss. *Dioritic Schist.*	DIORITE. Dioritic Gneiss. *Dioritic Schist.*		AMPHIBOLITE. *Hornblende Rock.*	
Augite.	*Augitic Schist.*	AUGITE HYPOSYENITE.	DIABASE. *Diabase Schist.*	DIABASE. *Diabase Schist.*			
Talc.	Talcose Quartzite. *Talcose Schist.*						STEATITE. *Talc Schist.*
GRANULITE.					GRANITE. Gneiss. *Mica Schist.*	SYENITE. Syenitic Gneiss. *Hornblende Schist.*	PROTOGINE. Protogine Gneiss. *Talcose Schist.*
GREISEN.		GRANITE. Gneiss. *Mica Schist.*	ALBITIC GRANITE. Albitic Gneiss. *Mica Schist.*	GRANITE. Gneiss. *Mica Schist.*			
HYPOSYENITE.	SYENITE. Syenitic Gneiss. *Hornblende Schist.*				MICACEOUS HYPOSYENITE.		TALCOSE HYPOSYENITE.
DIORITE.	ALBITIC SYENITE. Syenitic Gneiss. *Dioritic Schist.*						
SYENITE.			ALBITIC SYENITE. Syenitic Gneiss. *Hornblende Schist.*		MICACEOUS SYENITE Hornblendic Gneiss *Micaceous Hornblende Schist.*		TALCOSE SYENITE.

TABLE FOR ROCK DETERMINATION.

A. Crystalline—some of the constituent minerals having shining, lustrous surfaces; or the rock is fine, compact and hard.

- I. PHANEROCRYSTALLINE, consisting of minerals distinguishable with naked eye or pocket lens.
  - 1. QUARTZ the essential constituent of the rock.
    - (1) Massive or thick-bedded (QUARTZITE).
      - (*a*) Composed of fragments compacted but distinct.
        - (*aa*) The constituents are rounded pebbles, *Quartzose Conglomerate.*
        - (*bb*) The constituents are small grains, *Granular Quartzite.*
      - (*b*) Composed of grains completely blended or nearly so, *Vitreous Quartzite.*
    - (2) Thin- or moderately thin-bedded.
      - (*a*) Composed of separate grains, *Quartzose Schist.*
      - (*b*) Composed of a somewhat vitreous, silicious mass, { *Silicious Schist.* / *Jasper Schist.* }
  - 2. FELDSPAR alone with quartz.
    - (1) Structure massive, *Granulite.*
    - (2) Structure schistose, { *Granulite Gneiss.* / *Granulite Schist.* }
  - 3. MICA a leading constituent of the rock.
    - (1) Quartz alone with mica.
      - (*a*) Massive or thick-bedded, *Micaceous Quartzite.*
      - (*b*) Thin-bedded, arenaceous-granular, *Micaceous Sandstone.*
    - (2) Feldspar alone with mica, *Minette.*
    - (3) Feldspar and quartz with mica — either muscovite or biotite, or both together; texture coarse or fine; the feldspar whitish or reddish; the quartz without cleavage planes.
      - (*a*) The feldspar not in definite crystals, but fragments.
        - (*aa*) Massive, granular, *Granite* proper.
        - (*bb*) Thick-bedded, or sometimes thin-bedded, *Gneiss* proper.
        - (*cc*) Thin-bedded, mostly with little feldspar, *Mica Schist.*
      - (*b*) The feldspar in defined crystals, or some of it so; massive, *Porphyritic Granite.*
  - 4. HYDROMICA a leading constituent.
    - (1) Quartz alone with the hydromica.
      - (*a*) Massive or thick-bedded, *Hydromica Quartzite.*
      - (*b*) Thin-bedded, arenaceous-granular, *Hydromica Sandstone.*
    - (2) Feldspar alone with hydromica, *Hydromica Minette.*
    - (3) Feldspar and quartz with hydromica; texture coarse or fine; the feldspar mostly whitish or reddish, exhibiting cleavage planes; the quartz without cleavage planes.
      - (*a*) Massive granular, *Hydromica Granite.*
      - (*b*) Thick-bedded and sometimes thin-bedded, *Hydromica Gneiss.*
      - (*c*) Thin-bedded, mostly with little feldspar.
        - (*aa*) In conspicuous grains, *Hydromica Schist.*
        - (*bb*) Fine, with greasy feel (many former "talcose" schists), *Sericite Schist.*

5. **Amphibole** a leading constituent.
(1) The amphibole occurring as hornblende (commonest case).
(*a*) Hornblende alone present, *Amphibolite* or *Hornblende Rock.*
(*b*) Orthoclase alone present with hornblende, *Hyposyenite.*
(*c*) Orthoclase and quartz present, with often some biotite.
(*aa*) Massive, *Syenite* proper.
(*bb*) Thick-bedded, rarely thin-bedded, *Syenite Gneiss.*
(*cc*) Thin-bedded with little orthoclase, *Hornblende Schist.*
(*d*) Plagioclase alone present with hornblende.
(*aa*) The plagioclase acidic, associated often with some quartz or muscovite; color grayish-white to greenish, or olive green.
(*aaa*) Massive, *Diorite.*
(*bbb*) Thick-bedded, *Diorite Gneiss.*
(*ccc*) Thin-bedded, *Diorite Schist.*
(*bb*) The plagioclase basic, generally labradorite, associated with biotite and no quartz; texture coarse or fine; structure massive or thick-bedded, *Norite*, part.
(2) The amphibole occurring as actinolite.
(*a*) Massive and tough, *Actinolite Rock.*
(*b*) Thin-bedded, with some quartz, *Actinolite Schist.*
(3) The amphibole occurring as smaragdite (a light green hornblende) with a white or whitish labradorite in fine grains mottling the light green mass, *Euphotide.*

6. **Pyroxene** a leading constituent.
(1) Pyroxene alone present, in the form of augite, coarse or fine granular, *Pyroxenite.*
(2) Orthoclase present abundantly with little augite, *Augite Hyposyenite.*
(3) Plagioclase present with pyroxene (augite); texture granitoid or fine.
(*a*) The plagioclase acidic, ordinarily oligoclase, *Diabase*, part.
(*b*) The plagioclase basic.
(*aa*) The pyroxene lamellar (diallagic); the plagioclase a cleavable labradorite; texture granular, color reddish to dark gray and grayish black (Gabbro of some), *Norite*, part.
(*bb*) The pyroxene granular; the plagioclase anorthite or labradorite; texture fine, *Diabase*, part.
(4 Quartz present abundantly, with sahlite and some feldspar, *Pyroxene Schist.*

7. **Hypersthene** a leading constituent, generally with cleavable labradorite [physically like Norite, and by some so called], *Hypersthenite.*

8 **Epidote** the characterizing constituent.
(1) Epidote alone, or nearly so; texture fine granular; very hard; pale green, *Epidote Rock.*
(2) Epidote with quartz and feldspar, *Unakite.*

9. **Hydrous-magnesian** minerals in characteristic abundance.
(1) Talc alone present, in a massive amorphous state, *Steatite.*
(2) Talc with quartz and feldspar.

(*a*) Massive, *Protogine.*
(*b*) Thick-bedded, *Protogine Gneiss.*
(*c*) Thin-bedded, with little feldspar.
(*aa*) The quartz granular, *Talcose Gneiss, Protogine Schist.*
(*bb*) The quartz fine and nearly wanting, the rock mostly a mass of minute folia of talc, *Talcose Schist.*
(3) The magnesian mineral is chlorite; quartz and feldspar also present.
(*a*) The feldspar abundant; structure thick-bedded, *Chlorite Gneiss.*
(*b*) The feldspar scanty; structure thin-bedded, *Chlorite Schist.*
(*c*) The feldspar not discernible; texture very fine, structure slaty, *Chlorite Slate.*
(4) The magnesian mineral is serpentine.
(*a*) Color homogeneous dark green to greenish-black, *Serpentine.*
(*b*) Color mottled, greenish and white, being mixed with limestone ("verd antique"), *Ophiolite.*

10. ALUMINOUS minerals in characteristic abundance.
(1) The characterizing mineral pyrophyllite; color white, gray, or greenish-white; feel greasy; appearance that of a talc rock, *Pyrophyllite Schist.*
(2) The characterizing ingredient argillaceous, firmly indurated, cleaving into thin, even layers [Clay slate, Phyllite], *Argillite.*

11. CALCAREOUS rocks; hardness not above 3.
(1) Effervescence with dilute acid when pulverized.
(*a*) Effervescence with *cold* acid.
(*aa*) Rock chiefly calcareous, *Marble.*
(*bb*) Rock a variegated mixture with serpentine, *Ophiolite.*
(*b*) Effervescence only when *heated*, *Dolomitic Marble.*
(2) No effervescence; hardness about 2, *Gypsum.*

12. CARBON the characterizing constituent; color black or dark-brown.
(1) Rock distinctly stratified; hardness 2–2.5; lustre bright, often sub-metallic; iron black and frequently iridescent; fracture conchoidal; burns with a feeble flame of pale color, *Anthracite.*
(2) Rock unstratified.
(*a*) Lustre resinous; burns freely, *Asphaltic Substances.*
(*b*) Lustre metallic; streak black and shining; color iron black to dark steel gray; feel greasy, *Graphite.*

13. IRON the characterizing constituent; specific gravity 3.6 to 5.3.
(1) Streak black; specific gravity, when pure, 4.9 to 5.2; acts on the magnet, { *Magnetite Schist.* *Titanic Iron.*
(2) Streak red; specific gravity, when pure, 4.5 to 5.3, *Hæmatite Schist.*
(3) Streak dark reddish brown; acts slightly on the magnet; contains zinc, *Franklinite Schist.*
(4) Streak brownish yellow; specific gravity, when pure, 3.6 to 4, *Limonite Schist.*
(5) Streak white; sp. gr. of siderite 3.6 to 4.5; effervesces with hot acid, *Spathic Iron.*

II. **Microcrystalline** and **Cryptocrystalline** rocks—separate crystals or grains not discernible with a lens.	
A. Texture felsitic—partly microcrystalline, distinct minerals discernible only under high powers in thin sections.	
1. Structure massive or indistinctly stratified.	
(1) Color black or nearly black, sometimes greenish.	
(*a*) Massive or thick-bedded,	*Aphanite.*
(*b*) Thin-bedded, but obscurely so, compact.	*Aphanitic Schist.*
(2) Color whitish, reddish, or mottled.	
(*a*) Essentially orthoclastic (see page 27); silica intimately united; hardness quartz-like.	
(*aa*) Without imbedded crystals; color mostly red,	*Petrosilex.*
(*bb*) With imbedded crystals (or alternating bands) of quartz [Quartz Porphyry],	*Quartz Petrosilex.*
(*cc*) With imbedded crystals of feldspar,	*Porphyritic Petrosi'ex.*
(*dd*) With imbedded pebbles.	*Conglomerate Petrosilex.*
(*b*) Essentially plagioclastic, basic; hardness between feldspar and quartz.	
(*aa*) Without imbedded crystals,	*Felsite* proper.
(*bb*) With imbedded crystals (or alternating bands) of quartz,	*Quartz Porphyry.*
(*cc*) With imbedded crystals of feldspar [Porphyry],	*Porphyritic Felsite.*
(*c*) Essentially quartzose; felsitic texture not perfect,	*Jasper Rock.*
2. Structure distinctly bedded or even slaty,	*Felsite Schist.*
B. Texture colloid; lustre glassy; constituent minerals completely blended or nearly so,	*Rhyolite*, etc.
C. Texture glassy, lustre quite glassy; translucent or transparent; colorless or white,	*Vitreous Quartzite*, part.
B. Uncrystalline—fragmental or calcareous; distinctly stratified.	
I. Effervescence with acids, at least when pulverized and heated.	
1. Effervescence with cold acids; rock sometimes semicrystalline, sometimes with an earthy lustre.	
(1) Well consolidated,	*Limestone.*
(2) Partially consolidated, white or rusty,	*Chalk.*
(3) Unconsolidated, putty-like when wet; white,	*Marl.*
2. Effervescence only when heated.	
(1) Having the aspect of a limestone; often finely granular,	*Dolomite.*
(2) Aspect dark and earthy; often nodular,	*Spathic Iron.*
II. No effervescence with acids, or only very little.	
1. Quartz the predominating mineral.	
(1) The quartz fragments cemented together.	
(*a*) The fragments consist of rounded pebbles,	*Conglomerate.*
(*b*) The fragments consist of fine grains,	*Sandstone.*
(2) The quartz fragments uncemented,	*Sand.*
2. Clay the predominating ingredient.	
(1) The clayey ingredient somewhat indurated, but the rock fragile and breaking into thin layers,	*Shale.*

(2) The clayey ingredient not indurated.
(*a*) Mixed with various impurities; blue, red, dark, or white, *Clay.*
(*b*) In a state of purity; color white, *Kaolin.*

3. Carbon the characterizing constituent; color black or dark-brown.
(1) Rock distinctly stratified.
(*a*) Lustre bright, often submetallic, iron-black and frequently iridescent; fracture conchoidal; burns with a feeble flame of pale color; hardness 2 to 2.5, *Anthracite.*
(*b*) Lustre pitchy; fragile; hardness 2 or less; burning with a yellow, smoking flame; surfaces often showing vegetable structure [*Bituminous Coals*].
(*aa*) Softens and becomes pasty in the fire; has property of caking, *Caking Coal.*
(*bb*) Burns freely without softening; has no caking property, *Non-Caking Coal.*
(*c*) Lustre dull; color generally brownish [*Lignite*], *Brown Coal.*
(2) Rock indistinctly or distinctly stratified, with little or no lustre; highly bituminous, *Cannel Coal.*
(3) Rock unstratified.
(*a*) Lustre resinous; burns freely, *Asphaltic Substances.*
(*b*) Lustre metallic; streak black and shining; color iron-black to dark steel gray; feel greasy, *Graphite.*

4. Iron the characterizing constituent (1), (3) and (5) generally crystalline).
(1) Powder black; sometimes as black shore-sand, *Magnetic Iron Ore.* *Titanic Iron.*
(2) Powder red; lustre earthy; consolidated or pulverulent [*Red Chalk, Red Ochre*], *Hæmatitic Iron Ore.*
(3) Powder dark reddish brown; contains zinc, *Franklinite Ore.*
(4) Powder brownish yellow; partially consolidated, granular or pulverulent [*Bog Ore, Shot Ore, Yellow Ochre*], *Limonitic Iron Ore.*
(5) Powder white; effervesces with acids when heated, *Spathic Iron.*

STUDY XV.—*Sedimentation.*

Let us visit a spot overflowed by the last freshet. We go down to the border of the creek and find the flat grimy with the muddy slime deposited while the stream was out of its banks. The level meadow was quite covered by the water; and we can understand that many overflows must make material additions to the land. Indeed, the character of the soil here, and its very level surface, show that during times past this piece of ground must have been formed from sediments deposited at times of overflow. Deposits from rivers are called *fluviatile*, and the land resulting is *alluvial.* In Cincinnati at the time of great floods, the Ohio River, which then abounds in sediments, leaves a thick layer of fine sticky mud wherever the water stands — in streets, yards, cellars and the floors of first stories of the houses. Think of the enormous amount of mud which is thrown down along the whole course of the river wherever the overflow takes place. So the river becomes bordered by *alluvial bottoms*, except where the banks are too high for overflow. The same is true of the Connecticut, the Potomac, and all other rivers.

Let us go down by the pond; here we shall see other results of the process of sedimentation. Perhaps this pond is caused by a dam thrown across the stream. If so, your father or uncle may remember when the dam was first built; it was not a century, but notice how the pond is "silted up"; it is half filled with mud and sand washed in from the adjacent hill-slopes. Perhaps this pond is a little lake, with or without a slight outlet. You have seen many of them. They abound especially in our New England and Northern States. Suppose ourselves standing by one of these lakelets. It looks a little like the view in Fig. 25. The lakelet is bounded on most sides by elevated ground, but on one side the shore is low and marshy. The land stretches off several rods in a perfectly level marsh or meadow; then we suddenly reach the firm upland. Down by the water the marsh grows less and

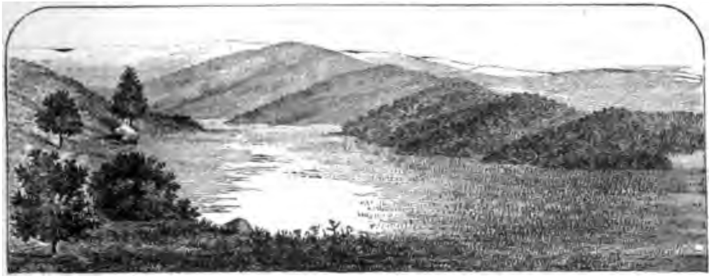


FIG. 25.—THE LAKELET SLOWLY FILLING. PROCESS OF SEDIMENTATION.

less firm. Even beyond the border of the water, some sedges find a situation suited to their natures, and still beyond, bulrushes and flags rise from water a foot or more in depth. On other sides, the nature of the lakelet border is very different. Now consider on which side the marshy border lies. It is almost always on the side opposite that from which the prevailing wind blows; that is, it is the easterly side — ranging from northeast to southeast. The leaves, grasses and twigs which float on the water surface are drifted by the winds toward the marsh, where they become lodged and go to decay. The resulting vegetable matter forms a dark, peaty layer on the bottom, which accumulates from year to year. It stretches from the land down and under the water. As the land grows, the marsh-grasses and sedges extend their area, and water-loving plants spring from the submerged portion of the peat. Thus, from year to year, the peat extends further along the bottom, and the land encroaches upon the lake. But suppose this process has been going on a thousand years; the land must have grown lakeward quite extensively. Indeed it has; and this level marsh or meadow shows how much land has been made in this way. Let us dig in this marsh. You know beforehand it is formed of black "muck." And now we see why the marsh is exactly level, and why it lies but very little above the surface of the water.

But here is another phenomenon. Underneath the muck or peat is a bed of marl; how came that there? Well, going down to the lakelet again, you see marl lying on the bottom; so of course, as the peat bed extends, it covers the layer of marl. An examination of the marl shows numerous dead shells — *univalves* or water snails, and *bivalves* or *mussels*. These are in all stages of decay, and it is evident that much of the marl thus originates. Living snails and mussels still abound in the water, especially near the shores, crawling on the bottom. But probably some portion of the marl results from precipitation of calcium carbonate from spring waters, as briefly explained in Studies II and XII.

If sediments are thus accumulating on the bottom from the deposit of calcareous matter, and from the wash of the land; and if the peat marsh is gradually encroaching, what must be the final result? Evidently, the lake must be filled, and a bed of peat underlaid by marl will occupy its place. Now you understand the origin of those numerous swales and bogs and tamarac swamps which exist in some regions. They are the sites of ancient lakes. Some of them have become sufficiently drained to be meadows, or even arable grounds. The old swamps, when thus dried, furnish our most productive lands, because they are filled with the very materials which supply the chief food for vegetation.

The growing swamp is not always on the lee side of the lake; it will be found, however, on the side toward which surface motion sets. Sometimes the position of contiguous hills deflects the prevailing winds from their normal direction; and sometimes a surface drift is imparted by the drainage of the lakelet.

We must study a little farther the results of river sedimentation. Look on a map of the Mississippi valley from Cairo to the Gulf of Mexico. The region presents but a very gentle slope, and the course of the river is wonderfully sinuous. For the whole distance, one looks out from the deck of a steamboat, over a wide alluvial plain, bounded, at a greater or less distance from the river, by high banks. Toward the gulf it expands in a triangular form, and that part is called the *delta*. Freqently the whole alluvial plain is so called. This plain is flooded by the high water of certain seasons — unless confined by a system of embankments. During overflows the sediments subside — the coarser first and the finer afterward. This is familiarly illustrated by the subsidence which takes place in a glass of water as shown in Fig. 26. We may suppose this is a glass of Mississippi River water with a little gravel added.

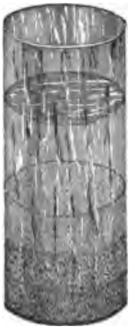


FIG. 26 ASSORTMENT OF SEDIMENTS IN TURBID WATER.

The alluvial deposit of the Mississippi has thus accumulated to the depth of ten, twenty, or even fifty feet. In Fig. 27 we

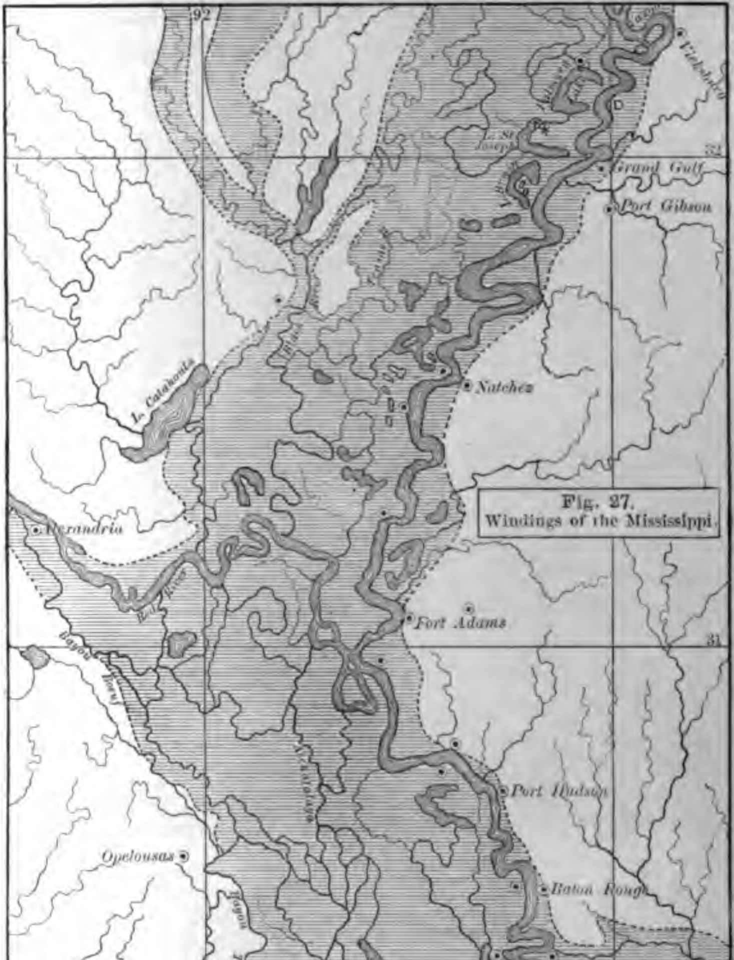


FIG. 27.—WINDINGS OF THE MISSISSIPPI FROM VICKSBURG TO BATON ROUGE.

present a map of a section of the river between Vicksburg and Baton Rouge, with shading to indicate the breadth of the alluvial belt. Through this belt, with its wonderful network of bayous of sluggishly moving water, the channel pursues its sinuous course, frequently striking the high upland, and affording sites for cities and villages, as at Vicksburg, Natchez, and other points. It will be noticed that the stream repeatedly doubles on itself, forming peninsulas. At many points it has completely worn the isthmus across, forming islands, and pursuing a new channel, as seen below Fort Adams. At other points, as near Grand Gulf and Port Hudson, the entrances to the old channels have been "silted up," and the old channels then remain as lakes. Thus Bruin Lake was cut off before the river was known to navigators; Lake St. Joseph before 1700, when the river was shortened twenty miles; and Palmyra Lake was formed by the Davis cut-off, *D*, in 1867, reducing nineteen miles to one. In one memorable instance this conversion of a peninsula into an island was effected by human agency. Notice the position of Vicksburg on the map, Fig. 27. During the late war, in 1862–3, a canal was dug across the U at *C*, for the passage of the federal gunboats, to enable them to shun the batteries erected on the Vicksburg bluffs. This canal has now become the main channel of the river, and the old channel remains a mere bayou of nearly still water, greatly to the detriment of the trade of the city. Sediment is constantly accumulating in it. Only one expedient seems practicable. The Yazoo river, which empties into the Mississippi a few miles above the city (see map), may be dammed, and its waters conducted through a canal into the Mississippi at the bend of the U above the city. This river then would scour out the bayou, and Vicksburg would stand on the Yazoo, two miles above its mouth.

When it is noted that this enormous alluvial deposit extends to the Gulf of Mexico, we gain some conception of the volume of sediments transported by the Mississippi. At its mouth the current is met by a body of salt water, over which the river discharges itself. Here the slackened motion results in the deposition of a vast volume of sediment known as the "bar." But another and finer portion of the sediment is borne to sea and taken up by the normal oceanic currents, which carry it to great distances before it finally settles down upon the ocean's bottom.

All the rivers which empty into the sea are similarly contributing sediments to be added to the layer accumulating over the bottom. Thus the oceans are filling, as well as the lakes; and the ocean sediments are burying, also, the remains of the molluses and fishes which lived in the water above their final burial place. The dredge brings up samples of the sediments for our inspection. They are coarser and more abundant nearer the shore, as we should expect; and the continental sediments cease almost entirely before the great abyss is reached. In the zone, from two to three miles in depth, we find a pretty uniform layer of a white marly substance known as "globigerina ooze," from the predominance of microscopic shells of *Globigerina*, a genus of Foraminifera, of which more will be learned in Part II. With these are numerous fragments of other organisms, especially of *Pteropods.* This substance when dried presents the appearance of white chalk; and in fact, white chalk is largely composed of similar organisms. At greater depths the admixtures with globigerina ooze diminish in quantity. At the greatest depths is found a layer of fine, homogeneous reddish-brown clay, composed of silica, alumina, and oxide of iron. This is supposed to be a residuum left after the solution of *Globigerina* and *Pteropod* shells by some peculiar action of the abyssal sea water.

EXERCISES.

How does moving water act to separate the finer and coarser particles? In a stream flowing from a steep ravine to a plain, what portion of the transported material will be deposited on the plain? What portion along the slope? Why this assortment? Why is the upper layer of sediment from a pool of turbid water finest? Is the alluvial deposit from the Mississippi fine or coarse? Why is this so? Describe a stream which would deposit pebbles. What do you know about the power of Alpine torrents? What effect is produced on rock fragments transported by water? Has water itself any power to wear the rocks? In what two ways do rocks disappear under the action of water? [See Studies II, III, and XVI.] In a mixture of fine sand, powder, and slime, how may water be used to separate them? Can you think of other moving waters besides streams which also exert an assorting action? What movements of the ocean do this? Why are the coarsest pebbles nearest the beach? Why are some beaches pebbly and others sandy? To what depth are the ocean waters stirred by winds and tides? What kind of sediments would be borne to the greatest depths? Why are the most projecting points of the coast rocky? Would marine animals generally prefer to live about such points? Why do we not find good shells along a stony coast? Mention some marsh which resulted from the filling of a lake. Ask some of the old citizens if they know any lake or pond which has been filled by sediments. Would you be surprised to find shells in a bed of dry peat? What is filling the Gulf of Mexico? What is getting buried by the sediments? Do you think the deposits are all uniform, or are they arranged in layers? What would cause a coarse layer? What a fine layer? Have all rivers deltas? What might prevent a river from having a delta? Mention a river without a delta. Mention rivers with extensive deltas.

STUDY XVI.—*Erosions.*

We have seen, in various situations, a great amount of turbid water. Some of this stands, for a time, almost motionless; some is hurried onward by running streams, and some is moved by winds and currents in lakes and seas. But in all situations, suspended sediments tend to settle, and will eventually settle, unless the agitation of the water is too great. We have seen that some of the material moved by waters consists of pebbles and larger stones. Some consists of sand in a coarser or finer condition. But all is nearly of the nature of the drift materials covering generally the surface of the land. That is, transported sediments are nothing but fragments of rocky formations, broken and ground and pulverized. Let us try and trace some of them to their sources.

Here, first, is the slime settled in a pool by the roadside. It is quite evident that the last rain washed the material from the roadway and the fields. On this declivity a more powerful current has cut a deep gully, which renders the highway almost impassable, and the bowlders, stones, pebbles, sand, and mud are strewn in order along by the fences, and across the flooded fields. The sediments are derived from the drift. Every rain-storm transports portions of the drift from the higher to the lower levels. Every rain-storm carries some of the soil from the ploughed fields, and leaves it in the bottom of the lake, or spread over the alluvial flat.

Let us go to the rocky gorge. Here, in ordinary weather, is a small stream, though noisy ; and it seems to have accomplished a great work. Usually the water is clear, and seems to move no material from its place. But how came this deep ravine into existence ? It is the work of *erosion.* You have seen the clear brooklet swollen to a torrent. At such time it rises to the level of the crumbling banks, and tears out stones and sand, and hurls them down to the foot of the gorge. The finer sediment is carried miles beyond into the gentler current of the river, or the standing water of the lake. Sometimes the banks of the gorge are rocky, but the roaring torrent cuts its way through them, and the strata stand in nearly vertical walls on either side. In southern New York, at many localities, are such deep ravines, cut through sandstones and shales, nearly horizontal in position. We give you in Figure 28 a view of one at Watkins' Glen, at the head of Seneca Lake. This is a very picturesque region, much frequented by tourists. Many other gorges may be seen along the Genesee River, in its course to Lake Ontario. Do not fail to notice the gorge and the falls at Rochester, when you pass over the Central Railroad.

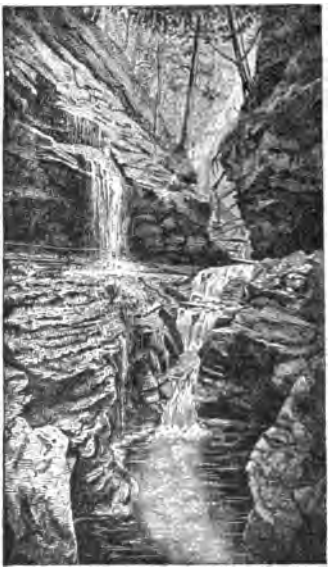


FIG. 28.—VIEW IN THE GORGE AT WATKINS' GLEN, N. Y. ("RAINBOW FALLS"), ILLUSTRATING EROSION BY WATER.

In the northwestern states are other examples of erosion equally beautiful and impressive. The Wisconsin River, in its course to the Mississippi, has cut a deep channel through a friable sandstone, giving rise to a great amount of charming scenery. One of the views is presented in Fig. 29. The student of geology is greatly favored in this fact, that the very data of his science are the most interesting features of the earth's surface. The greatest of rivers, the Mississippi, has also effected erosions worthy of its greatness, though unimposing, it must be confessed, in comparison with another river whose equal greatness belongs to a past age of the world. Along the upper Mississippi, high cliffs line the valley most of the way (Fig. 30). The Niagara, as every-one knows, has excavated a gorge which, with the "falls," its instrument, is the wonder of the world. We shall have to consider this in other connections. (See Figs. 305 and 306.) But the most stupendous examples of river erosion are found in the Far West. The Colorado has cut prodigious cañons through the

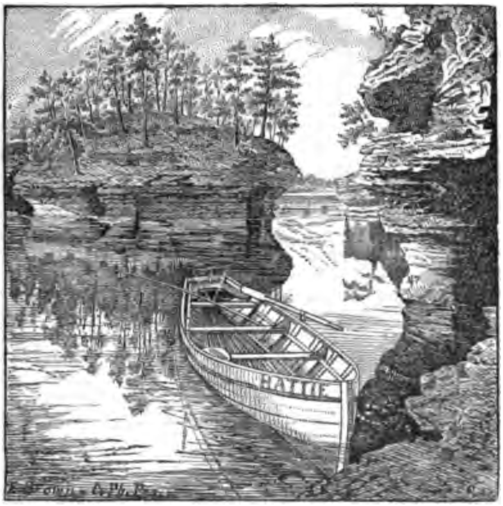


FIG. 29 --THE "DALLES" OF THE WISCONSIN, SHOWING RIVER EROSION.

horizontal strata to the depth of four, five and six thousand feet. Many of its tributary streams have excavated similar gorges. Thus much of the region is scarred and scored in a manner which renders it almost impassable. We cannot conveniently visit this region, but we supply in Fig. 31 a perspective view of the "Grand Cañon" at the foot of the valley of the Toroweap, and of some of the contiguous country. The total chasm presents itself in two stories. The walls of the outer cañon stand five or six miles apart, and about 2,000 feet high. The inner cañon is 4,000 feet wide and 3,000 feet deep. At the bottom flows the diminished river, about 300 feet across. The rocky beds which outcrop in the nearly vertical walls vary in colors from brilliant red to creamy yellowish and gray. But we must not enter here into any detailed statements. For these we refer the student to the glowing pages of Captain Dutton's description in "The Tertiary History of the Grand Cañon District," in the Report of the United States Geological Survey for 1881.

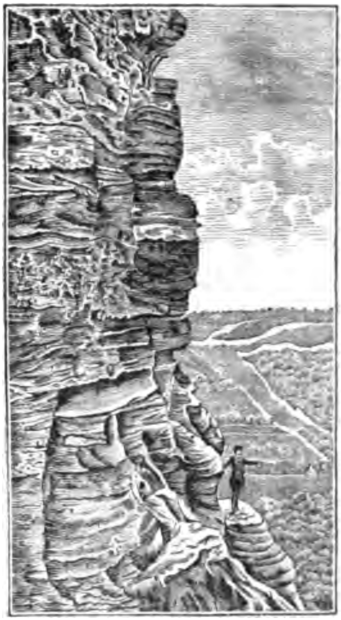


FIG. 30.—CLIFF ON THE UPPER MISSISSIPPI NEAR TREMPEALEAU, WIS., ILLUSTRATING RIVER EROSION. (Chamberlin.)

These examples, with others which may be familiarly known to the student, illustrate the destructive action of flowing water in all parts of the world. Aggregating the effects of thousands of years, we begin to understand how enormous has been the transportation of sediment into the sea through the agency of rivers, and how vast has been the destruction of the land. If we stand by any lake or ocean shore, we shall witness a different

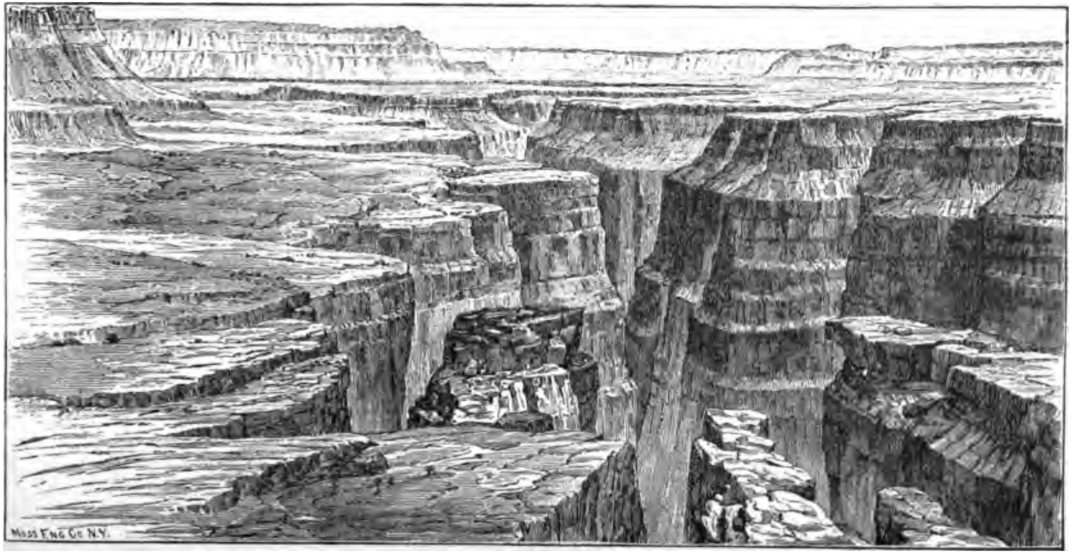

Moss Eng Co N.Y.

Fig. 31.—Grand Cañon of the Colorado at the Foot of the Toroweap, Looking East. (Dutton, in U. S. Geol. Surv.)

action of the same agent. Historical records assure us of vast wastage of the land on many an exposed coast; and we shall learn hereafter that ocean waters have in other ages covered extensive areas now dry land, and have worn down the surface hundreds and thousands of feet. The very cañon just mentioned is cut in a plateau which has itself been lowered by erosion to the extent of 10,000 feet; and this plateau occupies an area of 13,000 to 15,000 square miles. The student may calculate how many cubic yards the land has lost, and how many have been spread over the bottom of the sea.

The evidences of the great wastage of the land in times past can everywhere be seen. Sometimes extensive masses are undermined, and tumble down. This accelerates their final disappearance (Fig. 32). In the year 1248 a large part of a mountain in Savoy fell to the plain, under the action of frost. The mountain rose 4,000 feet above the plain, and was capped by 600 feet of limestone. The undermining of this mass caused the precipitation of sufficient material to cover nine square miles with fragments, and entirely bury five parishes, together with the town and church of St. Andre. In 1751 a series of avalanches fell during several days from a mountain near Servos, in Savoy, which sent up a cloud of dust visible twenty-five miles. The amount of material precipitated was 15,000,000 cubic feet. Many similar cases could be cited.

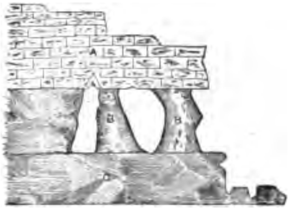


FIG. 32. — MAGNESIAN LIMESTONE UNDERMINED BY THE DISINTEGRATION OF A SANDSTONE BENEATH. (Chamberlin.)

This underminining process is the method of recession of water-falls, as will be shown hereafter (Figs. 305 and 306).

The central part of Tennessee — that known as the "central basin" — is a vast sunken area more than a hundred miles in diameter; and this has evidently been produced by the removal of many cubic miles of rocky material through some process of erosion in times past. All around the border of this basin rise the rocky walls of the remaining portions of the formations a hundred feet high, or more. In East Tennessee is another valley formed by extensive erosion. These are shown in the cut, Fig. 33. See also how the nearly vertical strata of the Unaka range have been worn down to mere stumps. Where have gone the continuations of these upturned strata?

We direct the student's attention to one more example. In Fig. 34 is shown the evidence of vast erosion in the Appalachians. Here the actual surface is shown along A B C. The slight elevation at A represents truly one of the ranges of the Allegheny Mountains. B represents the range known as Bald Eagle Mountain. Notice the foldings of the vast series of strata. Notice the mountain mass represented by E, which once rose 35,000 feet above the present surface, and all has been carried away by erosion. This section is in Centre County, and shows but a fraction of a full section across the Appalachian chain. But all the mountain elevations have been similarly worn down.

In very numerous cases singular columns of the eroded rock have escaped erosion. Sometimes, as in Monument Park, Colo-

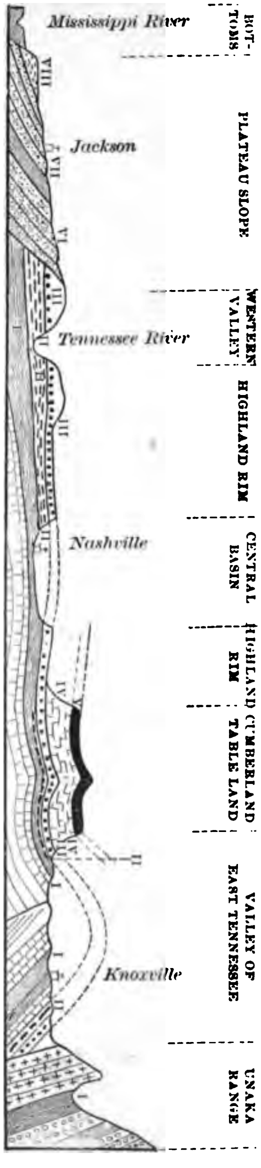


FIG. 33.—SECTION THROUGH TENNESSEE, SHOWING EROSION OF THE CENTRAL BASIN AND OF THE VALLEY OF EAST TENNESSEE. (Safford.) I, Cambrian; II, Silurian; III, Devonian; IV, Lower Carboniferous; V, Upper Carboniferous; VI, Cretaceous; VII, Tertiary; VIII, Post-Tertiary (Quaternary). See explanation in Study XVII.

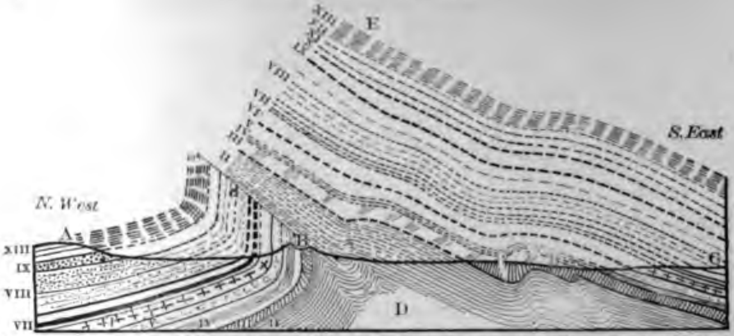


FIG. 34.—ILLUSTRATING ENORMOUS EROSION IN THE APPALACHIAN REGION. (After Lesley.) A, Allegheny Mountain at Snow Shoe; B, Bald Eagle Mountain; A B C, present surface — all above being swept away; D, probably a subterranean mountain of Eozoic rocks; II to III, Cambrian; IV to VI, Silurian; VII to IX, Devonian; X to XII, Lower Carboniferous; XIII, Coal Measures. Compare, for explanation, Study XVII.

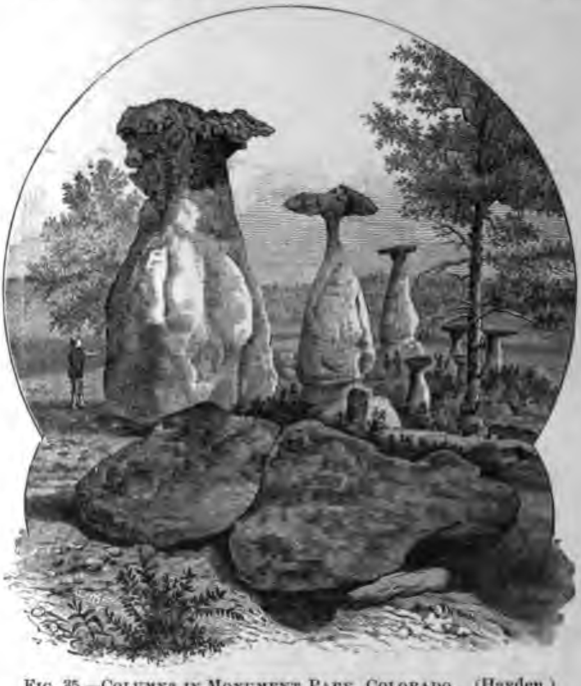


FIG. 35.—COLUMNS IN MONUMENT PARK, COLORADO. (Hayden.)

rado (Fig. 35), and in some parts of Wisconsin and Minnesota, they have been protected by a fragment of harder rock, which rests on them like a cap. Sometimes, as in the Plateau Province of Colorado, the rock masses around such columns have been worn away by streams of water.

We must not forget that mere weathering accomplishes much. This includes the mechanical action of beating rain, hail, and snow, and disintegrating frost, as well as the solvent action of water. On the dome of St. Paul's, in London, the more rapid weathering of the stone causes some of the fossils to project a quarter of an inch, as before stated. This observation, made in 1873, was after an exposure of one hundred and sixty-three years. At this rate 7,824 years would be required for the wastage of the stone to exceed that of the fossil to the extent of one foot. As the fossil itself wasted probably half as rapidly as the stone, we may safely assume that the wastage of the rock was not less than a foot in 4,000 years.

Many instructive examples of atmospheric decay may be seen among granite rocks. Here (Fig. 36) is a view of the summit of Mt. Hoffman, Sierra Nevada, showing the bowlder-like forms resulting from atmospheric action. A more striking example is shown in Fig. 37, where one of the granite ridges between the Temescal and San Bernardino ranges, in California, is weathered to a state

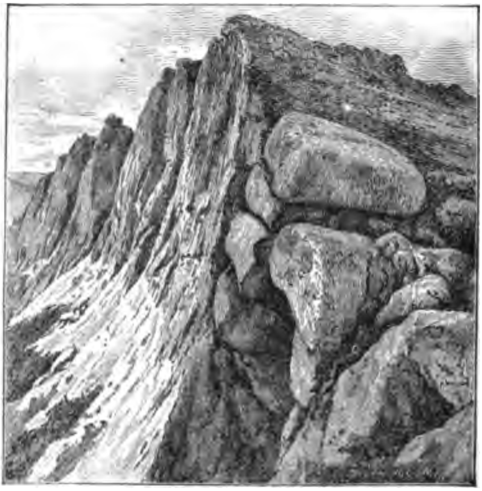


FIG. 36.—SUMMIT OF MT. HOFFMAN, SIERRA NEVADA, SHOWING DISINTEGRATION OF GRANITE. (Photograph.)

which presents the appearance of a bowlder-strewn surface. The weathering of granite is peculiarly apt to result in bowlder-like forms; and it can hardly be doubted that they have sometimes been mistaken for true glacial bowlders, even in tropical countries.

Much attention has been given to the wastage of the land generally. Some good authorities conclude that most continental surfaces are lowered by erosion not less than a foot in six thousand years. It has lately been calculated by T. Mellard Reade that when we take account, also, of wastage by solution, the surface of the basin of the Mississippi is lowered a foot in four thousand five hundred years; and that one hundred tons are removed annually from every square mile of the two Americas. The wastage of the land is called *denudation*.

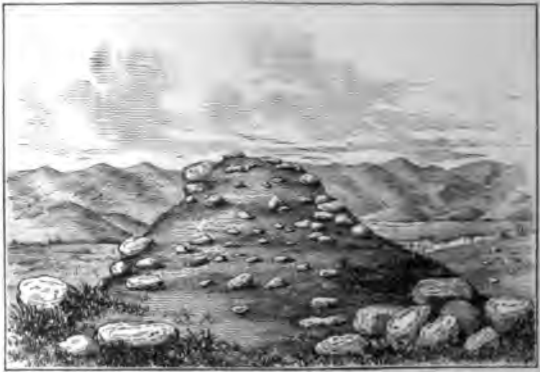


FIG. 37.—A RIDGE OF GRANITE WITH BOWLDER-LIKE MASSES RESULTING FROM WEATHERING. (Whitney.)

So we may learn that there has been vast destruction of the rocks during the course of many ages. They have been gradually reduced to gravel and mud, and even solutions, and carried off by the streams, to be laid down on the plains, or spread as sediment, if undissolved, over the bottom of the sea. [For other interesting illustrations of erosion see Figs. 85, 86, 95, 55, and 66.]

EXERCISES.

From what are sand and mud derived? Was the Mississippi mud ever in a rock condition? How might it be made rocky again? Would it become chalk? Could it be made a granite? What agents produce sand and mud from the rocks? How does frost act? How does a stream of water act? Mention some ravine excavated by running water. Is the excavation in drift or solid rock? Where has the material been carried? How far can you trace it in thought? What is the source of the sediments of the Mississippi? Which is most turbid, the Upper Mississippi or the Missouri? What is the cause of the difference? Whence comes the mud which forms the bar of the Mississippi? What is the color of the water in the lower Mississippi? What is the color of the water in the bayous of Louisiana and Mississippi? Has the Red River any delta? Would the erosions of the Missouri and the streams which feed it have any tendency to lower the Rocky Mountains? Where are the sources of the Ohio? Does New York state contribute anything to the bar of the Mississippi? What is the effect of denudation on the depth of the soil? Are the soils generally disappearing? In what situations are soils accumulating? If a hundred tons of material disappear annually from every square mile, to what extent does this lower the surface? [Calculate by assuming a mean specific gravity for the material.] Why do bed rocks project above the soil in some places and not in others? Is there any danger of the disappearance of the soil in a hilly country? Which surface lowers most rapidly, that of West Virginia or that of northern Illinois? Can you think of any reason why the plateaus of Colorado and Utah are more denuded than the surface of Louisiana? Suppose the stone on the dome of St. Paul's Cathedral in London is still one foot thick, how thick will it be (on the data given) one thousand years from now, if the cathedral is still standing?

STUDY XVII.—*Strata, and What They Teach.*

Most students of geology have been at some time in a stone quarry. There they have seen the quarrymen drilling and blasting and prying to remove slabs or layers of the rock. Such slabs are used in the stone walls of houses, sometimes in sidewalks, and sometimes, where they are thin layers of slate, they are employed in roofing. In quarries of granite or other crystalline rocks, the slabs are very thick, as you have already learned, and the stones are worked out in large cuboidal blocks. But in almost every case you will notice that the rocks in the quarry lie in layers, thick or thin. Each layer is a *stratum*, and two or more layers are called *strata*. We often also call them beds. If you go back to Watkins' Glen, Fig. 28, you perceive that the strata are quite thin or *slaty*, or, as we have before said, *thin-bedded*. The rocks shown in Fig. 29 are also thin-bedded. In both cases the strata are nearly horizontal. Almost everywhere the stratification or bedding of the rocks can be detected. We must try to ascertain how the bedded structure has been produced.

You have seen the brooks and rivers at work tearing down the land. You have seen the waves corroding the beach. You have thought on the slow disintegration of all the surface rocks by rains and frosts, and the perpetual wearing of the loose materials of the drift; and you have seen the waters carrying away the sediments to the sea. In thought you have followed those sediments in their distribution over the ocean's bottom. You have seen them lying and accumulating there, while dead shells and bits of coral and bones of fishes have been mingled with the growing deposit. What appearance must the sediments present in case a few acres of sea bottom could be taken out bodily and inspected? The sediments would consist of layers parallel with each other. They would be distinguished by different colors and by different degrees of fineness. Imbedded in the substance of the layers would be the relics of the animals which have lived in the sea. Is this a correct statement of what you would see? Think about it. The depth of the accumulated sediments would correspond to the time spent in their accumulation. You might look at them and reflect: "These layers of mud and sand were once far inland. They were once part of the soil of cornfields and gardens. Crops grew on them. The gully in the road was made by the removal of them. They came down the rivers. Some started on the slopes of distant mountains. The Missouri brought some from the gorges and summits of the Rocky Mountains. Some came out of the deep and gloomy cañons of the Colorado. Some came from the storm-torn bluffs at Long Branch or Coney Island or Gay Head. Some was yielded by the slowly dissolving promontories of Nahant and Marblehead."

That is what you might think; and such reflections are suggested by our observations on the processes of erosion and sedimentation. Now suppose the layers of sediments pressed by thousands of tons of weight. The deeper ones are so pressed when many feet of later sediments are deposited upon them. All are so pressed by the mere weight of deep water. They would thus be condensed into a solid state — like the paper pulp which is manufactured into car-wheels. They would be rocks. The rocks would be composed of *strata*. The thin layers would be *laminæ*. The shells and corals pressed in the rocks would be *fossils*. This is almost exactly what we have at Watkins' Glen, and in the majority of the rocks underlying the country. All our limestones, sandstones and shales were once just such sea sediments. The limestones, however, contain a very large proportion of matters contributed by the decay of shell-bearing animals.

You have already learned, however, that many rocks do not exhibit so distinct evidences of stratification as may be seen in ordinary sandstones, shales and limestones. In fact, most of our bowlders are only obscurely stratified, because rocks of this kind resist destruction more successfully than the rocks more distinctly stratified. These hard or crystalline rocks come to the surface, or *outcrop*, in most parts of New England and along our northern border. But, as before said, they are really stratified, and must be, therefore, of sedimentary origin like the others. They have, therefore, been *altered* since they existed in a condition similar to the others. This alteration is known also as *metamorphism*. The causes of it have been much studied; but there are still some mysteries about it. We understand, however, that great pressure, great heat, and chemical operations have had much to do with metamorphism. The effect of it is to render a rock less distinctly stratified, harder, more crystalline and less clearly fossiliferous. So metamorphism impresses characters which are easily observed.

When we find metamorphic rocks *in place*, that is, in solid ledges instead of bowlders or detached fragments, we generally find them underlying in relative position all the non-metamorphic rocks. This is plainly seen when we are able to trace them to their contact with other rocks. In Fig. 38, *a*, granite, and *b*, gneiss, are metamorphic or crystalline, and *c*, a sandstone, is uncrystalline. Now if we start from the highest point and travel toward the sandstone, we find, on reaching it, that it *overlies* the gneiss, as the gneiss overlies the granite. Now notice that the granite and gneiss not only *underlie* the sandstone at the point of contact; they are everywhere *stratigraphically lower* than the sandstone, even where their outcrops are *topographically higher* than the sandstone. This frequent arrangement of strata in respect to positions it is very important to observe and understand. An *outcrop* of one stratum at a higher level than another does not indicate whether it is stratigraphically higher or lower. We must take particular notice of the *dips* of the two strata. The *dip* is the direction in which they incline downward. In Fig. 38 the gneiss and the sandstone dip in the same direction; but as the gneiss has the greatest dip it passes under the sandstone. This is a case of *unconformability* — the two dips being different. The position of the sea bottom was different when the gneiss materials were laid down from its position when the sandstone materials were laid down. This single observation shows that the sea bottom has sometimes undergone a tilting or inclination, and that afterward later sediments have been laid down.

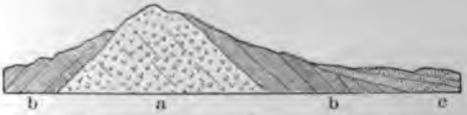


FIG. 38.—CRYSTALLINE AND UNCRYSTALLINE ROCKS.
a, Granite; *b*, Gneiss; *c*, Sandstone.

Look again at Fig. 38. Here is also a record of erosions. The gneiss on one side of the granite dips in a direction opposite to the dip on the other side. Suppose the granite could be pushed down so as to lower the gneiss to a horizontal position;

the gneiss of the two sides would become nearly continuous, only some portion would be wanting. Now we may fairly assume that the anticlinal position (both ways dipping) of the gneiss has resulted from the uprise of the granite from beneath the formerly horizontal gneiss. If so, the gneiss may have been originally continuous over the summit of the uplifted granite, and have been subsequently removed by processes of erosion. In such case, the outcropping extremities of the gneiss strata are the mere stumps of a wasted formation, and have been brought to a position higher than the sandstone by an *uplift* subsequent to the deposition of the gneiss sediments. We might reasonably conclude that there has been another uplift since the deposition of the sandstones; for they are also somewhat tilted. Thus the steep inclination of the gneiss may be the result of two or more uplifts. These things should be much reflected on.

From the simple stratigraphical observations thus far made, we may draw inferences like the following:

1. The duration represented by so enormous a pile of sediments as have come to our knowledge, must have been vast.

2. The *sea has covered all the land*, for all lands are underlaid by sedimentary rocks. The sea was once universal.

3. Some special action has been exerted upon the sediments to change them from earthy strata into crystalline rocks.

4. The land has resulted from an *upheaval of the bottom of the sea;* and upheavals have occurred *more than once* in the same region.

5. The upheaval of the sea bottom *bent* and fractured the strata, and threw them into *inclinations* more or less steep.

6. The work of *denudation* has removed the upper strata over the higher summits, and left the strata lower in geological position to stand at *higher elevations* than strata higher in geological position.

7. The movement of such enormous masses of rocks implies the exertion of *force inconceivably great.* The nature of this force will be an important subject for future study.

EXERCISES.

In what attitude are layers of sediments originally deposited? How, then, do we find them almost always in an inclined position as strata? Did you ever notice strata standing almost on edge? Explain how this could be. Give the history of strata whose edges come up to the surface of the earth. Draw a diagram showing how strata older in age may appear higher topographically. Draw one showing how newer strata may appear higher topographically. Draw a diagram showing conformability of strata. Draw one showing unconformability of strata. Suppose we have several strata, of which the lower is composed of pebbles and the others are progressively finer, what conditions produced this result? Suppose we can trace a stratum for many miles, and find it graduating from a conglomerate to a coarse sandstone, and then to a fine one; explain this. If we could trace it further, what further change might be expected? In what direction do older strata dip in reference to newer? In what direction do newer strata dip in reference to older? Can you give any reason why metamorphic rocks are generally more deeply seated than others?

STUDY XVIII.—*Fossils, and What They Teach.*

Now, once more let us carry our thoughts back to the bottom of the sea, where the sediments are continually burying the organic relics of the sea. Relics once buried become buried deeper and deeper. By and by some of them are a hundred, or even a thousand, feet beneath the ocean bed, and the sediments are becoming subjected to an enormous pressure, and are hardening into solid strata. Now, the amount of sediment in sea water far from land is generally small. The accumulation of successive layers is, therefore, very slow. We can understand that when they have become a thousand feet deep probably many thousands of years must have passed by. In that time the inhabitants of that part of the ocean may have changed greatly. The water is now a thousand feet shallower than it was. The deep-water species which dwelt there at first have migrated to a region where the water is still deep. Shallow-water species are here now. So the remains of the former kind are imbedded in the deep sediments, and those of the latter kind in the later sediments. But the ocean bottom sometimes changes its level. If it has been sinking here, the depth may be as great as at first; but if it has been rising, the depth is diminished even more than is due to the accumulation of sediments. Perhaps the nearest land has been more upraised, and the shore is now nearer to this spot; coarser sediments are now deposited here; the mud-loving populations have emigrated, and this place is taken by populations which like a sandy bottom. If, therefore, we could examine an extensive series of strata, we should find them *distinguished by their organic contents*, as well as by their constitution and color.

Now let us examine such a series. Every high rock precipice presents one; every deep river gorge presents one; the cañons of the Colorado present magnificent examples. Let us put different series together, so that we may inspect a continuous series from the oldest rocks known up to the latest. The column is, say, a hundred thousand feet high (see this in Fig. 39). What is shown? Something even more instructive than would have been anticipated. The lowest rocks are granites, and gneisses, and crystalline schists. They contain no fossils. Either there was no life in the ocean when they were formed, or its relics have been obliterated by metamorphism. But we must not say there was no life. Very rarely some obscure traces are seen in some of the serpentinous marbles well toward the bottom of the series. They are extremely simple in organization. We shall study them hereafter, and learn that they belong to the sub-kingdom of *protozoans* — the simplest of all animals. Above the level of the crystalline rocks we find organic remains quite abundant. Some of them are univalve shells; some are bivalves; some remind us of certain crab-like forms, and some are entirely strange and curious. But they are all *marine invertebrates*. We find nothing with a backbone; we find nothing which lived on the land; we find nothing nearly related to creatures which inhabit fresh water in our times.

The relics of marine invertebrates are found all the way from this level to the top of the series. But somewhat further up we encounter the bones, and teeth, and armor plates of fish-like creatures. True, they are not much like the remains of modern fishes; but we call them fishes. These creatures were at least bone-bearing, and though without backbones, they had something corresponding to the backbone. They were *vertebrates;* but they were marine vertebrates, if we may judge from the remains of other marine animals surrounding them. These very peculiar fishes do not continue to the top of our series; they seem to have lived only during a certain age of the world. (Compare Fig. 39.)

Next we come to a zone of strata, in which lie the vertebræ, skulls, and other remains of creatures related to our frogs and salamanders. They were of the type of *amphibians.* We feel justified in concluding that they lived on the land and breathed air. When they perished, their remains were borne into the sea by torrents and floods; and they left for us the record of their existence. With them we find, also, the relics of fishes less abnormal than the earlier ones; and also an abundance of shells and corals, different from the older ones, but still mostly unlike the familiar forms of modern times. (Compare Fig. 39.)

We are rising now toward the top of the series. For the first time we encounter the remains of *reptiles.* There are various reliable means of distinguishing them from the bones and teeth of all other vetebrates. These, of course, breathed air and dwelt mostly on the land. We notice a wonderful diversity among them, and we feel curious to learn what these various reptilian creatures were like. We shall take great delight in studying them by and by. Toward the top of this reptilian zone, where the reptilian remains are less bulky and less numerous, we detect some relics which must be ascribed to *birds.* In the midst of this zone we find also the teeth, bones, and scales of fishes resembling modern types.

Now we reach the upper zone of the long series of strata. Here still are the relics of marine invertebrates, of fishes like the last, together with occasional reptiles and birds. But here is also something very different. Here are the bones and teeth of mammalian quadrupeds. Here are the unmistakable relics of land-dwellers, which must have resembled the modern rhinoceros, pig, sheep, and horse, and other species of mammals. It is easy to perceive that they were not exactly like our modern quadrupeds, but they resembled them; they were land animals, and were *mammals.*

Notice that in all this succession we have not found a bone or a tooth which could be pronounced *human.* There is no reason why human bones alone should have disappeared. We are constrained to believe that man did not exist. All this succession of organic forms excluded man. He has appeared last of all, and all his remains, and all the remains of his industry lie upon the surface, or buried near the surface, in deposits laid down since the great work of rockmaking was ended, except in the depths still submerged beneath the ocean.

Arranging this succession in a more synoptical form, and placing the older types at the bottom, so as to stand in the actual order of superposition, it will appear thus:

7. MAN. Remains found on the mere surface of the earth.
6. MAMMALS. In the latest system of sedimentary rocks.
5. REPTILES and BIRDS. In the middle zone of the geological column.
4. AMPHIBIANS. The earliest air breathers.
3. MARINE VERTEBRATES. Fish-like, but not true fishes.
2. MARINE INVERTEBRATES. Molluscs, crustaceans, corals, etc.
1. PROTOZOANS (in crystalline strata). Simplest of all animals.

This succession of organic types, ranging from the bottom to the top of the stratigraphic series, is something very suggestive and very important. Let us think about it.

1. The variations among these fossil remains, from stratum to stratum, are much greater than would result from simple changes in depth of water or nature of the bottom. They are *variations in rank and in class type* and even in sub-kingdom.

2. The general tenor of the variations is an *improvement* in rank.

3. There must have been, correspondingly, a continuous and *progressive improvement in the conditions of the world* in their relation to organic life.

4. The *time* demanded for these changes *must have been vast*, if we may judge from the slowness of changes taking place under our observation.

5. In the earliest ages there *was no land;* all the species were marine.

6. If, as we have already inferred, the land resulted from upheaval of sea bottom, it is probable the first lands were of very *limited extent*, and gradually widened themselves with *successive upheavals*.

7. Since we know that in modern times, the existence of land elevations interferes with the normal circulation of the waters and the atmosphere, producing extremes of seasons, and abrupt climatic vicissitudes throughout the year, we may infer that when the lands were less developed, the seasons were *less extreme* and the *climates more uniform*.

8. These things being so, the primitive species of animals must have had a much *wider geographical distribution* than the later species.

These conclusions, indicated by our first glance at the records of historical geology, will be found confirmed by all our later studies.

The progress of life on the earth supplies the ground for a classification of geological time. The facts just stated mark off seven grand eras in the world's history, as shown in the right-hand column of Fig. 39. When these facts are combined with all the known facts of the succession of life, we are afforded a classification of geological time as shown in the two left-hand columns of Fig. 39. The larger time divisions are designated *eras* or æons, and these are subdivided into *ages*. On similar grounds, ages are further divided into *periods*, as indicated in the fourth column. The rocks receive the same classification as time, and the groupings bear the same special names. But, for the general designations of the various rock categories, terms have been selected ap-

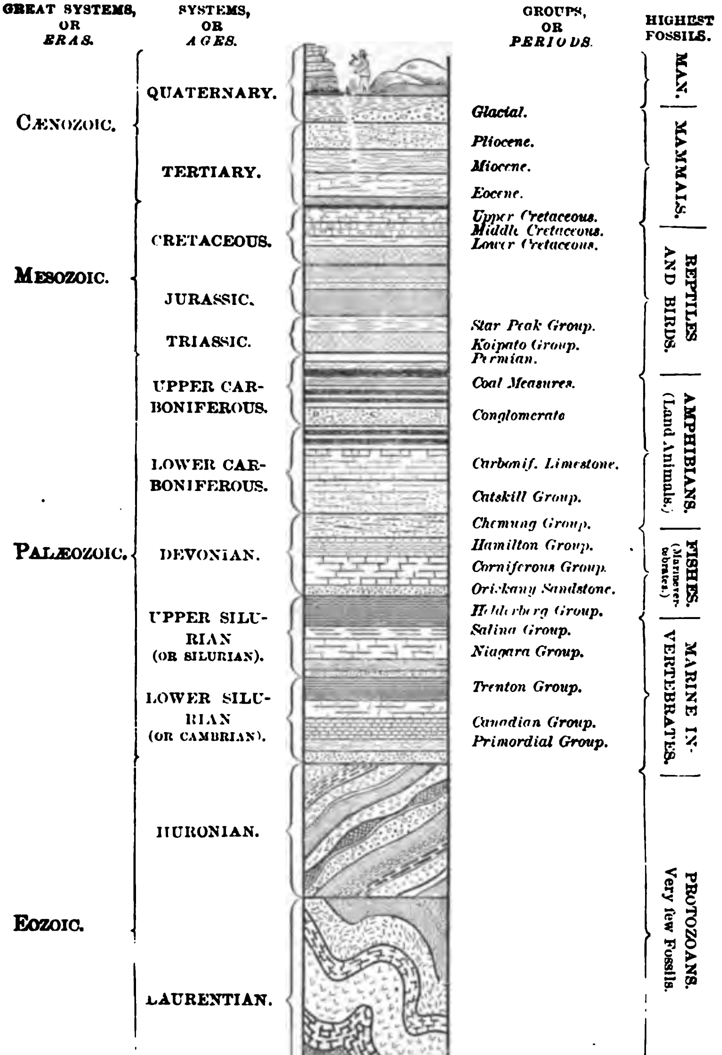


FIG. 39.—THE GEOLOGICAL COLUMN.

propriate to rock groupings, as shown at the heads of the first, second and fourth columns.

The following scheme illustrates the correlations of terms used in reference to rocks and time, as also, the recognized order of subordination in each category:

Time Categories.	*Rock Categories.*	*Examples.*
ERAS.	GREAT SYSTEMS.	EOZOIC, PALÆOZOIC.
AGES.	SYSTEMS.	LAURENTIAN, SILURIAN.
Periods.	Groups.	Primordial, Canadian.
Epochs.	Stages.	Acadian, Potsdam, Chazy.

EXERCISES.

Why do limestones afford more fossils than conglomerates? Why do we find different fossils in limestones and shales? What were the shales when the animal remains were accumulating in them? What kind of sediments accumulate near the shore? Explain how changes of level might change the character of the sea bottom. How might the upheaval of a promontory affect the bottom in a contiguous bay? Would you expect the remains of plants to be found sometimes embedded in the strata? Should these also be called fossils? Would they be marine or terrestrial plants? Would terrestrial plants be more abundant in the earlier or the later ages? Why? Should we say "Devonian Period" or "Devonian Age"? Correct the following expressions: Primordial System; Hamilton Age; Cretaceous Era; Mesozoic Period; Palæozoic Age; Chemung Age; Cambrian Group.

STUDY XIX.—*How the Strata are Disposed.*

We find the bed-rock everywhere — either at the surface or immediately underneath the unconsolidated surface materials. From what we have seen and reasoned it appears, therefore, that the ocean has rested over every portion of the earth's surface. We have seen reason to conclude, also, that there was a primitive period during which it covered the whole earth at once. The sheet of sediments then deposited must have enwrapped the earth somewhat like a coat of an onion — at least we may assume that for the present. But, as we have noted evidences of uplift and subsidence in the bed of the ocean, the primitive sheet became somewhat irregular. And further, since, as we have concluded, land resulted from upheavals of sea bottom, there must have come a time when sea sediments were not deposited over the whole earth, for some portions were above water. And finally, since the extent of the land appears to have been always increasing, the area of sea sedimentation has been continually decreasing, Hence we understand that *the oldest formations were universal, and later formations have been successively more restricted in extent.* We may therefore discover the limiting borders of a formation at any place which happened to be the sea shore at the time when the sediments were accumulating out of which it has been formed.

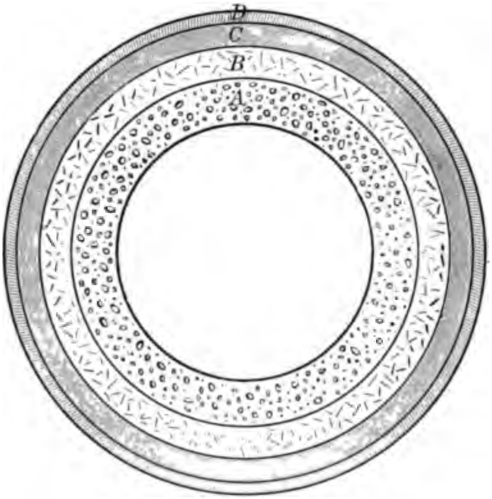


FIG. 40.—ERRONEOUS SUPPOSITION CONCERNING THE STRATA.

In addition, it will be remembered that erosion of exposed formations has always been in progress. Some have been eroded quite through, as shown in Fig. 38; their worn edges are presented to view, and thus we discover another important cause why most of the formations, as we find them, are not of universal extent.

We must not, therefore, conceive the entire series of rocky sheets as enwrapping the earth in the style shown in Fig. 40. The arrangements shown in Fig. 41 convey a juster impression; but it will be borne in mind that the stratified portion of the earth is vastly less than here represented; and the disturbances, also, greatly less. The diagram is simply intended to render clear the great fact of disturbance of the strata at successive epochs. Here it appears that the dislocations of the strata amount to some distortion of the earth's form. The ocean, *s s s*, rests in the depressions. These are not always, at least under the smaller bodies of water, *synclinal* basins — that is, resulting

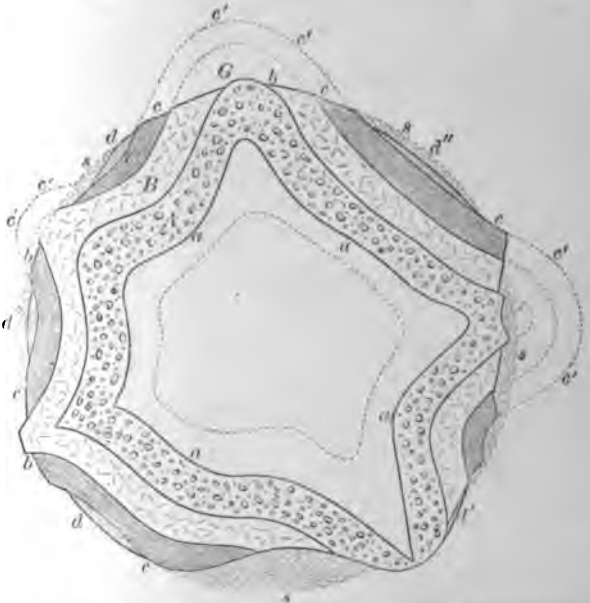


Fig. 41.—A More Correct Conception of the Strata — the Disturbances Greatly Exaggerated. The Great Systems are Represented by the Successive Bands: *A*, Eozoic; *B*, Palæozoic; *C*, Mesozoic; *d*, Cænozoic.

Note.—The systems of strata do not actually continue under the deep sea with undiminished thickness. They probably thin out gradually.

from the bending down of the strata. Some depressions result from erosion. Elevations above the ocean level constitute the land. It also appears that rocks of any age may occupy the surface. The oldest, or Eozoic, may rise to the summit of high elevations, or may lie, or even outcrop, at much lower levels than the later systems of strata. This diagram may be considered a *section* through the earth. The exterior portion, showing systems of strata, constitutes what is called the *crust*. Of the interior we know nothing from observation. The Eozoic strata which, in some places, as under *d* and *d''*, lie many thousand feet deep, in other places rise to the surface, and thus bring us information of the crust to such depths as they attain. The student should compare this diagram with Figs. 38, 34, 33, and 31.

Now we must explain some points which will require much patience and close attention. You will notice that the only system which completely surrounds the earth is the Eozoic, *A*. The sediments were deposited when the ocean was universal. In some places the Eozoic comes quite to the surface; in others, as at *a a a a*, it is *overlaid* by all the other systems, because in those regions the Eozoic remained depressed below the ocean level. In still other places, as at *b b b*, it is overlaid only by the Palæozoic; because either those places were not under the sea after the Palæozoic æon, or if they were, the later sediments have been removed by erosion. In still other places, as *c c c c*, the Eozoic is overlaid by both Palæozoic, *B*, and Mesozoic, *C*; because those regions remained sea bottom during the Palæozoic and Mesozoic eras, and no subsequent erosions have removed the sediments. There are only a few places, like *d d' d''*, where any Cænozoic can be seen, except drift or other Post Tertiary, which covers nearly all the land's surface, and is not represented in this diagram. The reason of this is, that the sea still covers nearly all regions covered by it during the Cænozoic æon. In some places, like *d'*, the Tertiary (Cænozoic) rests directly upon the Palæozoic, or even the Eozoic. This is because after the older strata were deposited, the region became dry land, and received no more sediments till the Cænozoic æon, when the region subsided and again became sea bottom. Thus a break in the succession of formations generally implies a period of elevation, followed by a period of subsidence.

If you look closely at this diagram, you will notice an appearance as if the Palæozoic and Mesozoic strata had at some former time extended further than at present. For instance, the dotted line, *c′ c′*, shows what may have been at some time the upper surface of the Mesozoic. If so, then the dotted line below this shows what may have been at the same time the upper surface of the Palæozoic. In fact, on all sides the arrangement of the strata looks as if they had been once wrinkled up, and then the higher places removed. This is somewhat like the truth; but we must not suppose the Palæozoic and Mesozoic ever extended quite over all the Eozoic which is now at the surface. We cannot say precisely how far they ever covered the Eozoic, because it is impossible to say how far they have been removed by erosion. We are certain, however, that they have been eroded to a great extent. And we can understand that the sediment produced by such erosions went partly into the sea, and was made over in the patches of tertiary which we observe at *d d d′ d″*.

If the dotted circle, *s s s*, represents the level of the ocean, you can see that some parts of the crust rise above it and form the continents; and those parts which rise highest are the mountains. You see, also, that all the systems of strata extend under the sea.

Now fix your attention on the *d* near the lower side of the diagram, a little to the left of the middle. The rocks there are Cænozoic, and you see a *section*, or cut, right through them and the rocks under them. This section shows what is the surface extent of the Cænozoic area there, in one direction. Here it is —the distance from *m* to *n* in this little cut, Fig. 42. We do not know how broad this Cænozoic area is in the other direction, but let us suppose it a little oblong in form; then its other diameter may be represented by *o p;* and *m p n o* will be a *map* of the Cænozoic area of which a section is shown in Fig. 41 at *d*, near the lower side of the figure. But then on one side, *b*, of this Cænozoic section is a section of **Mesozoic strata. Let us take the length of this Mesozoic section and lay it off from *m* to *r* on the side of the map, Fig. 42. As the Mesozoic on the other side is covered by the sea, we may represent the sea as bordering the Cænozoic, and may lay down as much of it as we please**—say from *n* to *q*, on the other side of the map; and may assume that the sea shore leaves the Cænozoic area at *s s*. Then the distance from *r* across to *n* is the whole diameter of the Mesozoic area to the sea, including the portion covered by the Cænozoic. The breadth in the other direction is not known; but we may assume it as extending from *t* to *u*. The whole size of the Mesozoic area not covered by the sea will be shown by *v t r u w*. Lastly, the Palæozoic when laid down on a map will give a belt surrounding the Mesozoic, as shown on *x y z*. So this is a *geological map* showing three systems of strata; and Fig. 43 shows the appearance of a section across it.

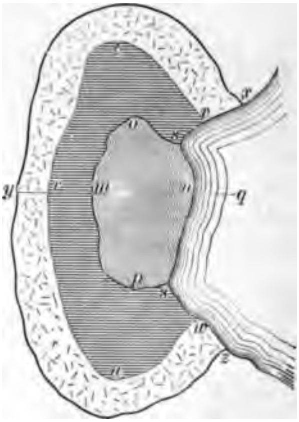
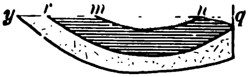


Fig. 42.—Map of the Region around *b d c*, Fig. 41.



Figs 43.—Section along the Line *y q*. Fig. 42.

Now, once more. Fix your attention on the point *G* in Fig. 41. If we proceed to make a map of the region around this point, it will look something like Fig. 44. Here you see the Eozoic in the middle, and the newest strata around the border. Here, also, the ocean bounds the area on one side. Notice particularly the difference between this map and the other. There the strata dipped from all sides toward the centre; here they dip from the centre toward all the sides. This is shown in the section as seen at *G*, Fig. 41, and better in Fig. 45. Here the Mesozoic, *c*, dips under the ocean, *s*, on one side, and under the Cænozoic, *d*, on the other; the Palæozoic, *b*, dips under the

Cænozoic, *c*, extending on one side under the ocean; the Eozoic, *G*, dips in both directions under the Palæozoic. From such observations we induce the important principle that the dip of a formation is always *toward newer rocks and away from older rocks.*

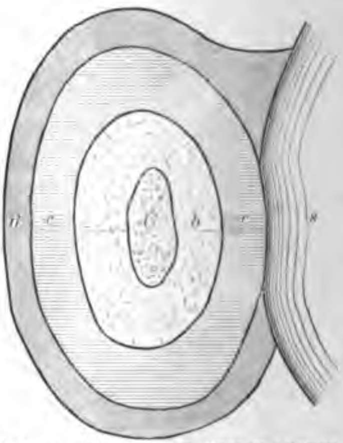


FIG. 44.—MAP OF THE REGION AROUND *G*, FIG. 41.

Now, for a more detailed and extensive section through the earth's crust, let us glance at Fig. 46. This is not intended to show what would be seen in any particular region, but what would be seen in a good many different regions. The various geological phenomena which would be seen in many different regions are here all brought together. So this is not a *real* but an *ideal* section. But the section is not imaginary. Everything shown is real somewhere. It embraces many features to be considered later in our course, and we shall frequently refer to it. For the present, it illustrates in another way the succession of strata, and their modes of superposition and outcrop.

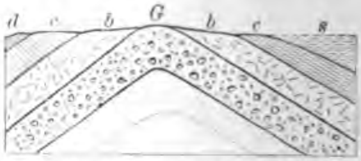


FIG. 45.—SECTION ALONG THE LINE *d s*, FIG. 44.

EXERCISES.

In Fig. 42, if we travel from the centre to the circumference, do we pass from newer to older rocks, or from older to newer? If we stand near the circumference, which way do the strata dip? Do they dip toward and under newer strata, or away from them? If we bore a deep hole at the centre of Fig. 42, what systems of rocks will we pass through? If we stand near the circumference of Fig. 44, which way do the rocks dip? Do they dip toward

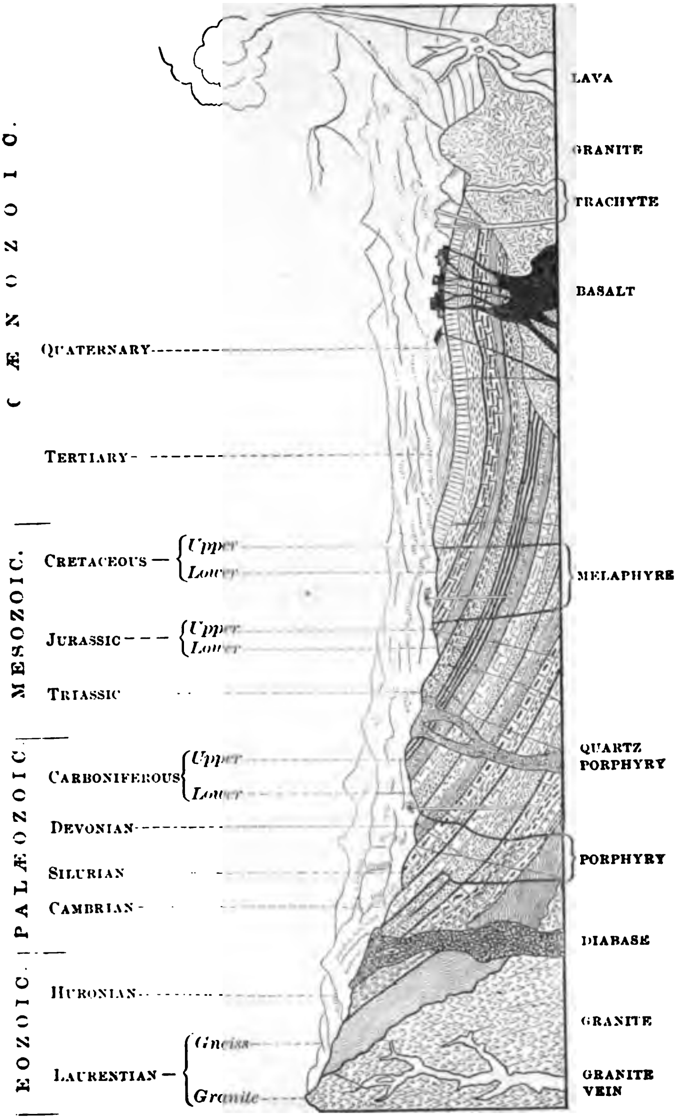


FIG. 46.—IDEAL SECTION OF THE EARTH'S CRUST.

the older rocks, or away from them? Must strata always dip toward newer rocks, and away from older rocks? Suppose you bore a deep hole near the margin of Fig. 44, what systems of strata would be passed through? Suppose you bore at the middle of Fig. 44, what rocks will be passed through? Must a geological area necessarily be circular? Suppose the ocean should wear away two-thirds from the area mapped in Fig. 44, could you then make a geological map of the region? Try it. Point out places where the Palæozoic outcrops in Fig. 41. Show where the Eozoic outcrops. What system of rocks least completely enwraps the earth? How could it be that Cænozoic rocks should rest on Eozoic, with no Palæozoic or Mesozoic between them? Make a geological map of the region extending from *G* toward the left, through *c*, *d*, and *s* to *b*, in Fig. 41.

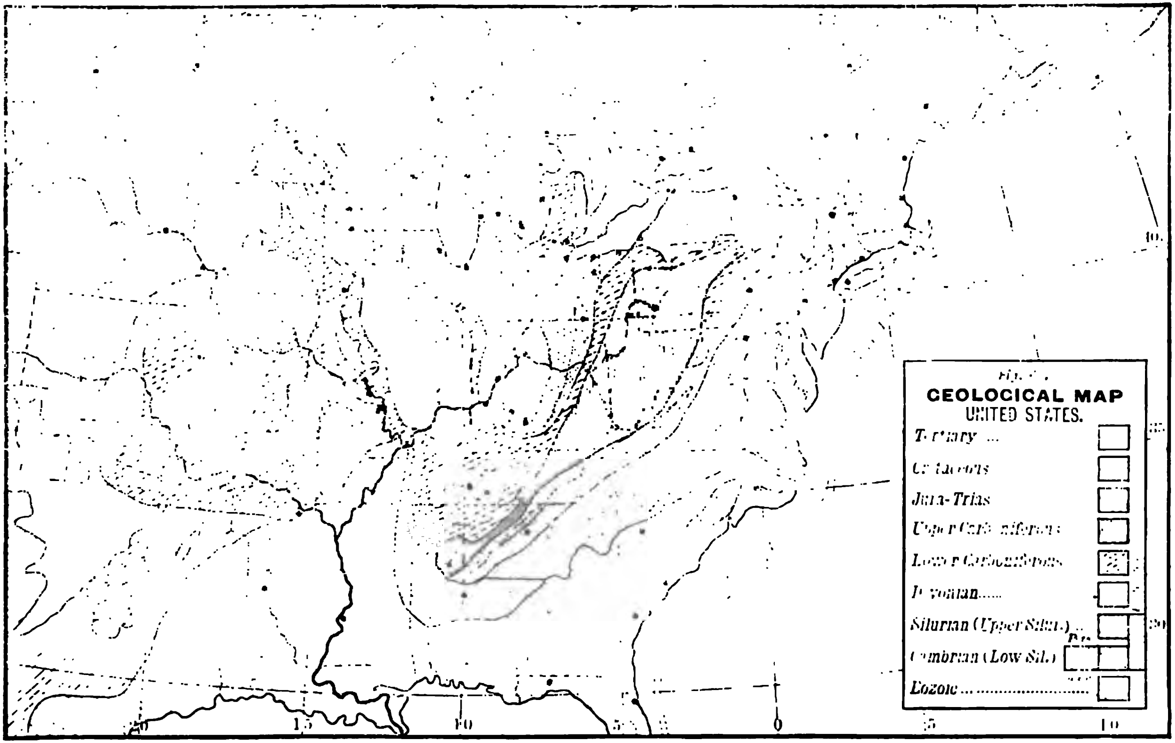
STUDY XX.—*Geological Maps.*

The subject of geological maps is another one requiring thoughtful attention, but one of the very greatest importance. The comprehension of geological maps is a great aid in the comprehension of geological facts and doctrines. In our last Study you observed small areas, as in Figs. 42 and 44, marked in such a way as to indicate the regions where certain systems of strata come to the surface. You understand, from Figs. 38 and 41, that no formation occupies the surface universally— for we except the quaternary, or drift. You understand that each formation comes to the surface in many different places, and in other places is covered by newer formations, or was never deposited. You understand, consequently, that the whole surface of the land is composed of areas of outcrop of the various formations. We may, therefore, take a map, and color or mark these various areas according to the formations which come to the surface. Now, most that we can learn about the earth's geology comes from a study of surface formations. If we are seeking for coal, or iron, or fossils, we can do but little more than study the formations at the surface. Hence, a geological map of the surface conveys most important information. The geological investigation of a region consists very largely in perfecting a geological map of it.

Now, I wish to offer you a geological map of the United States. The map, Fig. 47, covering two pages, embraces the whole United States except Alaska, though it must be confessed some of the region west of the Black Hills is delineated only in a very general way. This is a *real* map, which attempts to represent things as they are — though not with much detail. In one corner is a "legend," which indicates what systems of strata are mapped. These are the same as the "systems" in the "Geological Column," Fig. 39, with these exceptions: The Laurentian and Huronian are here thrown together as Eozoic; the Triassic and Jurassic are thrown together as Jura-trias, and the Post Tertiary (or Quaternary) is disregarded, except in some districts west and southwest of Great Salt Lake, since this is understood to be everywhere present, covering all other formations.

Taking up the eastern portion of this map, fix your attention first on the areas marked Eozoic. One large area lies north of the Great Lakes and the St. Lawrence River; another lies along the eastern flanks of the Appalachian chain of mountains, extending from Pennsylvania through Maryland, Virginia, North and South Carolina and Georgia, into Alabama. These two Eozoic masses pass *under* all the intervening strata, and meet together. As the Eozoic strata are the oldest known, the strata on both sides of an Eozoic area must be newer than Eozoic, and must overlie the Eozoic. As the dips are always *away from* the older rocks, it must be that the rocks along the eastern side of the Appalachian Eozoic dip toward the southeast, and those along the western side toward the northwest. And so the rocks along the border of the Canadian Eozoic must dip directly away from it. That is, along the valley of the St. Lawrence River, the rocks next the Eozoic must dip southeast; in the region north of Lakes Ontario and Huron, the dip must be south; in eastern Wisconsin, the dip is southeast, and in western Wisconsin it is southwest.

Southeast from the Appalachian Eozoic, we have very little except Tertiary strata. These, then, overlie the border of the Eozoic, and dip southeastward, extending to the Atlantic Ocean. Northwest of the Appalachian Eozoic, we find strata indicated by


GEOLOGICAL MAP
UNITED STATES.
Tertiary ...
Cretaceous
Jura-Trias
Upper Carboniferous
Lower Carboniferous
Devonian......
Silurian (Upper Sil.)
Cambrian (Low Sil.)
Eozoic ....
20
15
10
5
0
5
10
40
35
30

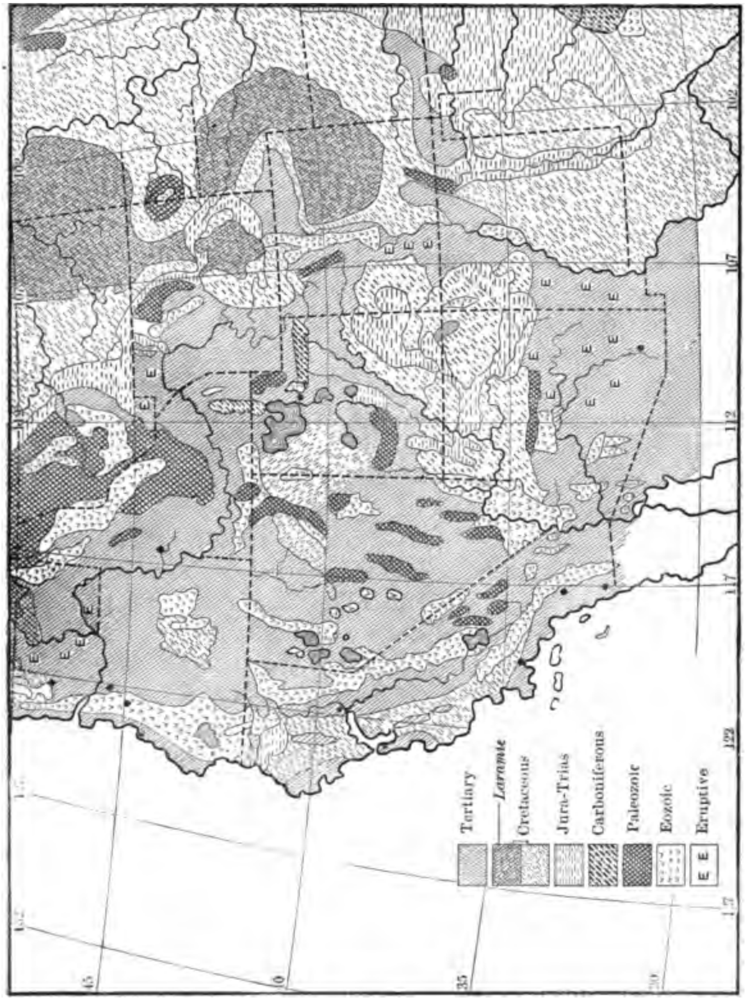


FIG. 47.—CONTINUED.

full oblique lines in one direction, and broken oblique lines in the other direction. These are explained in the "legend" to mean that the rocks are either Cambrian or Silurian (Lower Silurian or Upper Silurian, as some geologists prefer to say), but we have not yet ascertained which. These must dip northwesterly, away from the older Eozoic, and *toward* the newer Upper Carboniferous. Passing under all the Carboniferous, they come to the surface again in Tennessee, Kentucky, Ohio and Indiana, where we have learned them well enough to distinguish both Cambrian and Silurian (or, as some say, Lower and Upper Silurian). On the north, Cambrian and Silurian come up along the two shores of Lake Ontario. From this region the dip is southward all the time until we reach central Pennsylvania. In southwestern Ohio, the Cambrian, which comes up from the southeast, soon dips down again toward the northwest, and passing under Michigan and Lake Michigan, comes up again in eastern Wisconsin. Now, try and follow the Cambrian and Silurian up and down all the way from the Appalachian Eozoic.

You must not be content to simply read these descriptions. You must, by all means, follow the systems of strata on the map. When they go under, your thoughts must follow them. When they appear in view again, your thoughts must see them coming from under the newer strata. You must look *under* the surface of the map and *see* the solid, thick crust of the earth, with its various strata curved and overlapping, and discontinuing and beginning again, disappearing and outcropping, just as I describe them. If you do this, and perform an abundance of such exercises as will be given you, the study will soon be easy and delightful. If you do not, you will *never* have a good knowledge of geology.

Now let us continue the explanation of the map. On the southwestern border of the Wisconsin Eozoic you see Cambrian overlying it, and thence dipping southwesterly under Silurian, Devonian, Lower Carboniferous, and Upper Carboniferous. We can trace it, in thought, under all these systems, into Missouri and Kansas. We might reasonably expect the Eozoic to come to the surface again in the region farther southwest, but it scarcely succeeds in revealing itself. You will notice one patch in the Indian Territory, and one in southern Texas; but nearly all that region has been covered by Jura-trias, and then most of that has been covered by Cretaceous. Even upon the top of the Cretaceous are some patches of Tertiary.

In New England you will notice considerable areas marked Eozoic; but in *some* cases we only know that the rocks are crystalline like Eozoic, while they may be in reality only later rocks hardened and crystallized by *metamorphism*. You observe, however, a patch of Upper Carboniferous in Rhode Island, and a belt of Jura-trias running through Connecticut and Massachusetts. Farther north you will notice that the valley of the Connecticut is underlaid by Cambro-silurian rocks — that is, rocks either Cambrian or Silurian.

In the Adirondack region of New York is an interesting Eozoic area. This connects with the Canadian Eozoic by a narrow neck across the St. Lawrence River. The strata all around this Adirondack area dip away from it. This is a case somewhat like the Eozoic area in Wisconsin. On the other hand, the centre of Michigan is an area of Upper Carboniferous, and since the surrounding strata are all older they all dip toward the centre of Michigan.

Now let us vary the method of study. Suppose we stand on the southern side of Lake Ontario, the map shows that the dip of the rocks is south; for at that point we have Silurian, while to the south are the (newer) Devonian and Lower and Upper Carboniferous; and, according to the rule, the dip is *toward* the newer and *away from* the older in Canada.

If we stand at Milwaukee, the dip is eastward, for Milwaukee is on the Silurian, and eastward we have the Devonian and Lower and Upper Carboniferous in Michigan. Lake Michigan must also cover a portion of the Silurian and much of the Devonian. If, on the contrary, we stand at the St. Clair River, the dip is westward on the same principle.

Again, if we stand at Sandusky, Ohio, we are on the Silurian;

and if we walk straight to Cincinnati, we walk a long distance on Silurian, and then come to Cambrian. Then, if we continue our travel to Nashville, Tenn., we pass again over Silurian, a narrow belt of Devonian, a broad belt of Lower Carboniferous, and then come to a very narrow streak of Silurian again (too narrow to show on the map at this place, though it can be seen south of the Cumberland River), and end our journey on the Cambrian. Should we continne southward to Mobile, we should pass off the Cambrian directly upon the Lower Carboniferous, which extends into Alabama. Then, in the neighborhood of Tuscaloosa, we should pass upon the Upper Carboniferous, and beyond this, to the overlying Cretaceous, and should find Mobile on the Tertiary.

If we should travel from Albany to Boston, we should start on Cambrian rocks and pass to Silurian rocks. Before reaching central Massachusetts we should pass to rocks which are not fully determined — perhaps Cambro-silurian — and perhaps an outcrop of Eozoic. Crossing the valley of the Connecticut would be found Jura-trias rocks resting horizontally in a trough excavated in the older rocks. Those on the map are not extended far enough north. Beyond this valley we should find again rocks which are perhaps Cambro-silurian. Beyond these we should have Eozoic rocks for the greater part (all Eozoic on the map) until reaching Boston. All these things, and a thousand others, may be studied out on the map.

EXERCISES.

If you travel in a straight line from Detroit to Milwaukee, what systems of strata will you pass over? What if you travel from Mackinac to Cincinnati? What between Oswego and Plattsburg? What between Charleston and Nashville? State the dip of every system of strata passed between St. Louis and Chicago. Between Duluth and Lake Michigan. Between Saginaw and Springfield, Ill. Between Springfield and Cincinnati. Between Cleveland and Pittsburgh. What is the dip of the strata at Cleveland? What at Green Bay? What at Binghamton, N. Y.? What at Utica, N. Y.? Suppose you bore an artesian well at Lansing, Mich., what systems of strata will be passed through? What if you bore at Charleston, S. C.? What if you bore at Hartford, Conn.? What if you bore at Peoria, Ill.? What if you bore at Galveston, Texas? What if you bore at Montreal, Canada? Would an artesian well bored at Cincinnati pass through the Silurian? Or the Devonian? How could you travel from Albany, N. Y., to St. Paul without passing off the Cambro-silurian? How from Cairo to Cape May without passing off the Tertiary? How many great patches of Upper Carboniferous (Coal Measures) are shown on the map? Into what states does the Appalachian coal area reach? Into what states the Illinois coal area? Into what the Kansas coal area? Into what the Michigan? Into what the Rhode Island? Which state has the largest area of Eozoic rocks? Which next? Which has the largest area of Tertiary? Which state contains the greatest number of different systems? Which contains the fewest different systems? What states have the largest amount of soft rocks? What ones have most Palæozoic rocks? Give the names of the cities indicated by black dots on the map, and state what system of rocks each is located on.

NOTE.—The student, during his elementary course, ought to construct a geological map of the eastern United States, covering about the same ground as the one here presented. It would be desirable to make it on a larger scale, and also to employ a system of colors as indicated in the introduction.

STUDY XXI.—*Geological Sections.*

The student cannot take too many exercises on the geological map. He should become familiar as possible with the surface distribution of the formations. This is *geographical geology.* Such a map is a picture of the geology at the surface. But, at the same time, a careful study of it leads to important *inferences* in reference to the deeper geology. So you must not be content to look merely upon the flat surface of the map. It is not enough even to learn the location of the different colors lying on the surface. You must think of each color or system of markings as an outcropping of something which goes down beneath the surface to some other region, where it outcrops again. You must think which way it goes beneath the surface — that is, what is its *dip.* The rule already given determines that. So when you look on the geological map, you will learn to look *into* it, and far beneath the surface. You will see the whole solid framework of the rocks which underlie a country.

Now, we shall undertake some exercises which will give us the power of penetrating into the depths of the solid crust.

With the geological map before us, we will try to construct some geological *sections*. That is, if we could cut straight down along the line between two points which may be selected, to the depth of some thousands of feet, and then look at the cut edges of the strata, what form and arrangement would they present to us?

To begin with a simple case, let us construct a section across the state of Michigan from Detroit to Grand Haven. We will first draw a line, *G D*, Fig. 48, to represent the distance along the surface between the two points. We suppose ourselves facing north. We notice that Detroit stands on the Devonian. Take the distance from Detroit to the western border of the Devonian, and lay it off from *D* on the line *G D*. This distance extends to *a*. Next, lay off from *a* the distance which corresponds to the breadth of the Lower Carboniferous in the direction from Detroit to Grand Haven. This stretches to *b*. Thirdly, lay off the distance which our route passes over the Upper Carboniferous. This takes us to *c*. Fourthly, lay off the distance to the western border of the Lower Carboniferous; this takes us to *d*. Finally, lay off the short distance to Grand Haven, on the border of Lake Michigan. This takes us to *G*.

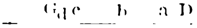


FIG. 48.—PREPARING FOR A GEOLOGICAL SECTION.

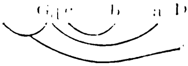


FIG. 49.—PROGRESSING WITH A GEOLOGICAL SECTION.

Next, we have to consider what is the dip of the strata at each point. On our principles, the dip is *toward* the Upper Carboniferous from both ends of the line. Draw lines down obliquely, according to the dip, from *a*, *b*, *c*, and *d*, Fig. 49, the boundary points between the formations. Then, knowing that the Lower Carboniferous, which dips down westward in the eastern part of the state, is the same which comes up to the surface from the eastward, in the western part of the state, we can connect the lines representing the lower and upper surfaces of this system. That is, the upper line will extend from *b* to *c*, passing down under the Upper Carboniferous; and the lower line will extend from *a* to *d*, passing under both Upper and Lower Carboniferous. The dip of the strata from *D* must pass in the same direction as from *a* and *b*. But notice that Detroit is not on the eastern limit of the Devonian. The line from the eastern limit — wherever it is — will pass some distance under Detroit, as at *e*. We need not know where it comes up to the surface. It is somewhere to the eastward, but we may cut it off at *e*, as we are only required to construct the section to Detroit. That line, then, ending at *e*, shows the bottom of the Devonian. Passing westward, it will come up at the west side of the Devonian, wherever that is. But the first system west of Lake Michigan is the Silurian, and the place for the bottom of the Devonian is between it and *d*, near Grand Haven. The western outcrop of the bottom of the Devonian seems to be *in the bottom of Lake Michigan.* This belief is confirmed by observing that on the map, the outcrop of the Devonian strikes the south end of Lake Michigan, and seems to pass under the lake. It comes mostly from under the lake again in the region of Grand Traverse and Little Traverse Bays, and Mackinac. We will therefore assume that the western outcrop of the Devonian is under the lake. We will also draw a little depression to represent the bed of the lake.

Instead of seeking for the western outcrop of the bottom of the Devonian, we might say as we did about the eastern outcrop, that it does not concern us to find it; we know the bottom line passes at some distance under *G*, and in that position we may draw it, and let fall a perpendicular from *G* to it — as from *D* to *e*.

So far we have assumed that the surface of the earth is a dead level from Detroit to Grand Haven; but, if we happen to know that the center of the state swells up a little, we should so represent it. We ought, indeed, to know this; because, if you look on any map of Michigan, you see the streams all flowing from the interior into the surrounding lakes. If, then, we show the surface configuration, our section will be a geological *profile.* Here it is in Figure 50, but on a scale twice as large. In completing the section we may bear in mind that the Silurian, which outcrops at Milwaukee, passes under Lake Michigan and the state of Michigan, and we may so represent it, though a section across Michigan does not require this. It would be proper, also, to represent the Cambrian under the Silurian, since we see from the map that on the west of Milwaukee it passes eastward under the Silurian. And, finally, we notice that in central Wisconsin the Eozoic passes southward under the Cambrian; and we may fairly assume that it would appear beneath the Cambrian under Michigan if we were able to make actual examination. So we fill in the lower left-hand corner of our section with the marks indicating Eozoic. Now the section is complete.

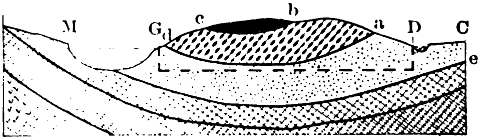


FIG. 50.—COMPLETED GEOLOGICAL SECTION BETWEEN DETROIT AND GRAND HAVEN, MICH.

We have, in fact, extended the section farther west than was required. We might have cut it off at Grand Haven. Also, we have carried it deeper than necessary. All that is essential in a section from Detroit to Grand Haven is shown by the broken lines.

Next, let us construct a geological section from the Eozoic north of Lake Ontario to Williamsport, on the Coal Measures of Pennsylvania; and let us suppose ourselves facing east. Draw a line, *E W*, Fig. 51, to represent the length of the section. This may be the same length as the distance on the map, or any multiple of that distance. However the length of the line chosen compares with the distance, all the intervening distances must be in the same proportion; or, if we know the distances in miles, we may lay them off from a scale. The number of miles may be got from a "scale of miles" given on a good map. When this is done, allow a little space — the proper space, if known — to the right of *E* for the distance to the southern margin of the Eozoic; and fix on a point, *a*, for the border of the Cambrian. The dividing line between the Cam-

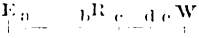


FIG. 51.—PREPARING FOR A GEOLOGICAL SECTION.

brian and Silurian is under the lake; let us locate it under *b*. The southern limit of the Silurian will be at *c*. The southern limit of the Devonian, determined from the map, will be at *d;* and here the Lower Carboniferous begins. The southern limit of the Lower Carboniferous, which is the northern limit of the Upper Carboniferous, will be at *e*. Then the southern extremity of our section will be at *W*, just over the border of the Coal Measures.

Now, we understand that all these rocks dip southward. So we draw lines from the points *a b c d e*, Fig. 52, to represent the dip, and terminate downward at such points as to produce a neat figure showing all that is required. Then we may fill in the lines and characters chosen to represent the various systems.

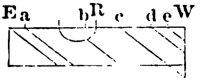


FIG. 52. – PROGRESSING WITH A GEOLOGICAL SECTION.

Notice, that it is customary to represent the dip somewhat greater than the reality, unles the real dip is steep enough to give a convenient breadth to the section. Notice, also, that this makes the thicknesses of the formations too great to be in due proportions to the distances along the surface. The section therefore has a "vertical scale" greater than the "horizontal scale," and the section is a distorted one, not a natural one. We always make the two scales the same if practicable.

We have constructed this section thus far on the assumption of a dead level from end to end. But we ought always to represent the relative elevations of different points as well as we can. In fact, geologists often take very great pains to ascertain the levels of different points. If the region where *E* is located is somewhat elevated, we should so represent it. And if we know that a high bluff of strata extends along the south shore of Lake Ontario, we should so represent that. An improved section between the two points would be as shown, Fig. 53. This is made on a scale four times as large as the other, which is too small for convenience. Here we notice a surface slope from north and from south toward Lake Ontario. Also a slope from both directions toward the Chemung River, whose place is shown by *e*. These things are not all shown on the geological map; but if you can, in any way, obtain information about the configuration of the surface, that should be introduced into your section. You will often have to refer to your geographical atlas to learn where places mentioned are located. The directions in which streams run will also show you what regions are more elevated and what are less elevated. The surface, also, always slopes toward streams. The region between streams is always somewhat elevated; but the amount of elevation is less in a country nearly level than in one having considerable slope.

The following is the way we complete the geological profile. Having laid down the necessary points along a horizontal line *A B*, draw vertical lines from these points, as shown, Fig. 53, and draw as exactly as you can, a line *E P* to represent the surface of the earth. The points *a c d e*, where this line intersects the vertical lines, indicate the bounds of the different formations. From these points we may draw lines to represent the dip and the thickness of each formation. (Those who have access to the *New York State Geological Reports* will find in Vol. IV, plate VII, a better proportioned drawing of the above profile; but it is *ten feet long.*)

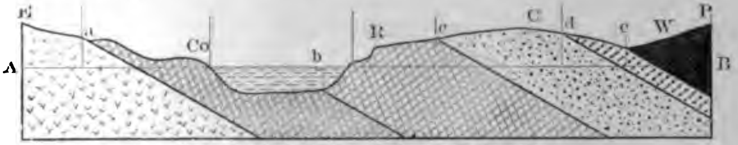


FIG. 53.—COMPLETED GEOLOGICAL SECTION.
E, Canadian Eozoic; *Co*, Coburg; *R*, Rochester; *C*, Corning; *W*, Williamsport.

You ought to take a great deal of exercise on the geological map, and especially in the construction of sections. No matter if it requires two or three days to finish one study.

Let us construct a section or profile from Nashville to Savannah. Here it is (Fig. 54). You will notice that the Cambrian east of Nashville is not known to be overlaid by Silurian; and when we trace it to the east of the Appalachians it is so metamorphosed that we are unable to say whether the formation is Cambrian or Silurian, and so it is simply put down on the map as Cambro-silurian. After passing the dome of the Eozoic, we find it overlaid directly by Tertiary strata, and we must so represent it. Not unlikely, however, some strata, intermediate in age between Eozoic and Tertiary would be found beneath the Tertiary if we could make exploration. The Tertiary passes under the waters of the Atlantic.

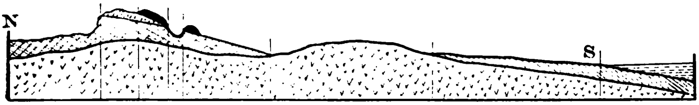


FIG. 54.—SECTION FROM NASHVILLE TO SAVANNAH AND THE ATLANTIC OCEAN.

EXERCISES.

Jake 3.

Construct sections as follows: From Madison, Wis., to Chicago. From Chicago to St. Louis. From Sandusky, Ohio, to Nashville, Tenn. From Mackinac to Cincinnati. From Montreal to Albany. From New York city to Oswego. From St. Louis to Cincinnati. From Cincinnati to Newbern, N. C. From St. Paul to Chicago. From Cairo, Ill., to Cincinnati. From Kingston, Ont., to Chicago. From Detroit to Fortress Monroe. From Cleveland to Cincinnati, and thence down the Ohio to its mouth. The student may also inspect the section, Fig. 33, and see whether it agrees with the geological map.

STUDY XXII.—*Thermal Waters.*

Everyone is familiar with the diurnal influence of the sun's rays on the earth's surface temperature; and every one has noticed that at night the surface cools to some extent. These diurnal fluctuations of temperature diminish downward in amount, and at the depth of about thirty-two inches disappear altogether. But there are also seasonal fluctuations, and these can be traced to a depth of about fifty feet. The depth, however, varies with the amount of the seasonal fluctuation. It would be less, for instance, in Florida than in Manitoba. But we may assume fifty feet for a mean. This implies that a thermometer buried at that depth would indicate a constant temperature throughout the year.

Just above this depth the influence of summer would produce a slight rise, and the influence of winter a slight depression. But the winter and summer influences are each about a year in reaching this depth and dying out. Each is about six months in reaching a depth of twenty-five feet. That is, the July influence is felt in January at a depth of twenty-five feet; and the January influence is felt in July at the same depth. Accordingly, water from a well of this depth might really be colder in summer than in winter.

If we carry our thermometer below the depth of fluctuating temperature,—that is, below about fifty feet—we find the temperature of the earth continually higher. We experience this in mining operations, where the temperature sometimes reaches eighty or one hundred degrees, or even more; and work would be impossible without means for introducing air from above. We experience it in tunnelling mountains, as Mont Cenis and Mont St. Gothard. We observe it in the temperatures of the water of *artesian wells*. These are wells bored down to some porous and water-bearing stratum, whose outcrop is some distance away at a higher level than the place of boring. In general, for such depths as we have been able to reach, the temperature averages about one degree higher for every fifty-one feet of descent. The deepest artesian well ever bored is at Sperenberg, near Berlin, Prussia. Its depth is 4,172 English feet (4,042 Flemish), and the bottom temperature is 118° Fahrenheit (38°.25 Réaumur). As the temperature at fifty feet was 54°.74 Fahrenheit, the mean rate of increase was one degree for sixty-five feet of descent.

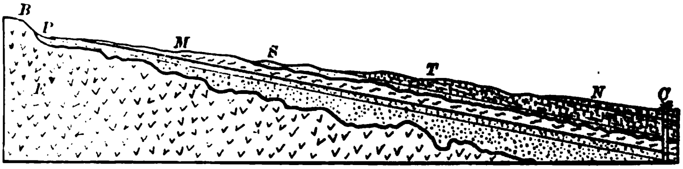


FIG. 55.—AN ARTESIAN WELL AT CHICAGO.
C, Chicago. *B*, Baraboo, Wis. *E*, Eozoic Quartzite. *P*, Potsdam Sandstone. *M*, Lower Magnesian Limestone. *S*, St. Peter's Sandstone. *T*, Trenton and Galena Limestones. *N*, Niagara Limestone. (See Fig. 39.)

There seemed to be a diminishing rate of increase at the greater depths. Indeed, it can hardly be considered probable that a constant rate should continue indefinitely. At an assumed rate of one degree for fifty-one feet, it is easy to calculate at what depth the temperature of boiling water would be reached, knowing the mean annual temperature of the place. But it will be borne in mind that under the pressure due to any depth beneath the surface, water would retain its liquid state at temperatures above 212°. At a pressure of ten pounds to the square inch above atmospheric pressure, the boiling temperature is about 239°.

Now, it may be inferred from what we have already observed and reasoned, that many strata which present their edges at the surface, extend down to the depth of hundreds or thousands of feet. This may be concluded, even from Fig. 41, or better from Fig. 46, where an artesian well is shown starting in Lower Jurassic strata and reaching a water-bearing stratum in the Upper Carboniferous. Surface water following the course of such a stratum, *a*, Fig. 56, would become heated. If at such depth a fault or fracture of the crust should be encountered, the water might rise to the surface by hydrostatic pressure, precisely as through an artesian boring; and thus a warm spring would result, as shown in Fig. 56. In the case of the springs at Bath, England, *a* is in the Mendip Hills, the temperature of the water is 120°, and the depth of *B* must be about 3,500 feet, the mean of the climate being 50°. Many warm and hot springs undoubtedly result in this way. In other places, as at Tuscan Springs, Cal., no faulting of the strata exists. Here, Fig. 57,

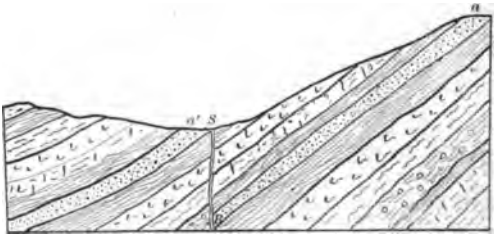


FIG 56.—GEOLOGY OF A WARM SPRING.
a, porous stratum receiving water at the surface, and intercepted by a fault at *B*, at such depth that the temperature of the water is over 100°, whence it rises along the fissure, and forms a warm spring at *S*. *a'* continuation of *a*.

the Cretaceous strata simply present an anticlinal and a fracture through which the water rises from such depth as to have been heated. The steep dip of the Cretaceous sandstone would soon reach the requisite depth. From that they rise eastward, and come to the surface along the ancient shore of the Cretaceous ocean which bathed the western flanks of the Sierra Nevada. Along that outcrop the supply of water is probably received.

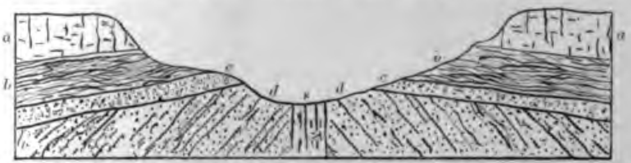


FIG. 57.—SECTION AT TUSCAN SPRINGS, SACRAMENTO VALLEY, CAL. (Whitney.) *a*, *a*, Basaltic Lava; *b*, *b*, Volcanic Ash and Scoriæ; *c*, *c*, Conglomerate; *d*, *d*, Cretaceous Sandstone; *s*, Springs.

The water of hot springs has great solvent power, and thus, very frequently, the spring delivers *mineral water*. Calcium carbonate and silica are thus very often brought to the surface. As the water cools, much of the mineral matter is precipitated on the surfaces over which it flows, and we get deposits of *tufa* or

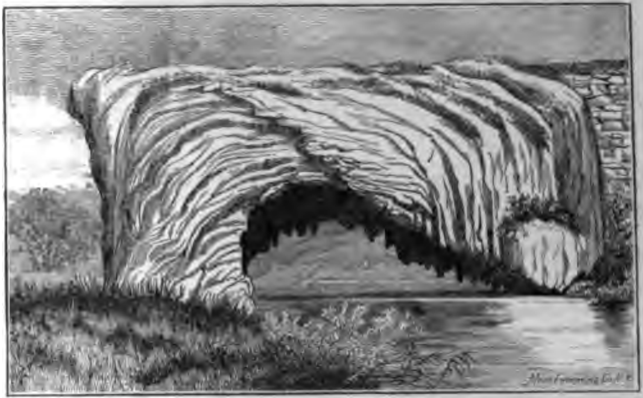


FIG. 58.—NATURAL BRIDGE OF TRAVERTIN FORMED BY AN INCRUSTING SPRING AT CLERMONT, FRANCE. (Scrope.)

sinter. Relief of the pressure tends also to cause the water to give up a portion of its mineral, precisely as in the case of common springs, which we considered in Study II. These tufaceous deposits sometimes acquire enormous extent.

In more numerous cases warm springs are found in proximity to volcanoes. In central France, especially in the departments of Cantal, Haute Loire, and Puy de Dome, is a district of extinct volcanoes, and here the phenomena of warm springs and their deposits are developed on a vast scale. At Clermont the deposits from a calcareous spring have formed an elevated natural aqueduct two hundred and forty feet in length, and terminating in an arch thrown across the stream it originally flowed into, sixteen feet high and twelve feet wide. (See Fig. 58.) Very extensive deposits occur in Italy and other European countries; but the most remarkable are found in the Yellowstone National Park,

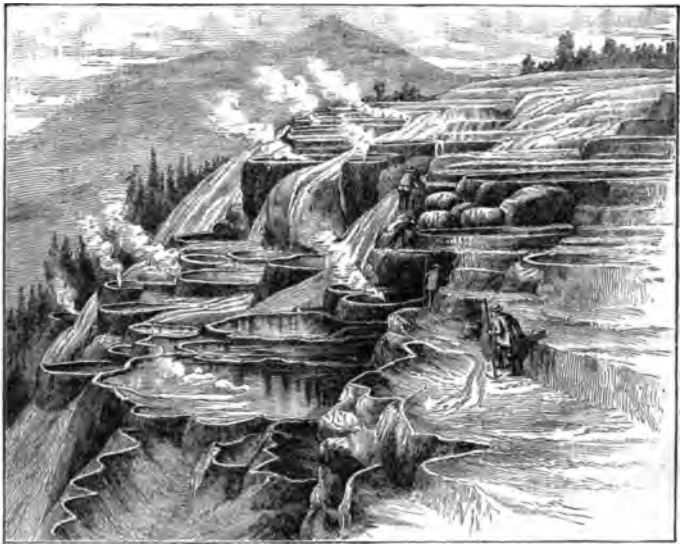


FIG. 59.—BASINS AT MAMMOTH HOT SPRINGS OF GARDINER'S RIVER YELLOWSTONE NATIONAL PARK. (Peale.)

where Peale enumerates 2,195 hot springs. These springs are also located in a volcanic district. In Fig. 59 is given, from Hayden's report for 1878, a view of a group of these springs which have built a curious series of basins. Very similar effects are produced by the thermal springs of New Zealand, Asia Minor, and other regions.

Many of the springs of the National Park present the phenomena of geyser action, or periodic ejection of hot water with great force, sufficient in some cases to throw it to the height of one or two hundred feet. Peale enumerates seventy-one geysers. In Fig. 60 is presented a view of the "Giant Geyser" in action. The crater has been formed by deposition of a mineral known as *geyserite*. It rises ten feet above the platform, and at base measures twenty-four feet by twenty-five, diminishing to eight feet at the top. Its depth is twenty-five feet. The temperature of the water is about 198° Fahrenheit. Its eruptions are some days apart, but the volume of water discharged is enormous, and the altitude attained is two hundred to two hundred and fifty feet. The power required to produce this result causes the earth to tremble, and a deep rumbling sound to be emitted. The so-called geyserite is, in other words, a *silicious sinter*. Silica is held in various proportions in these waters (from eight to fifty-four per cent), and is thrown down, as Peale thinks, in consequence of evaporation; but cooling and relief of pressure probably conspire.

A geyser in action is a striking geological phenomenon, and much speculation has been had in reference to its mechanism. The explanation which seems most satisfactory is that proposed by Bunsen. The water accumulating in the geyser tube is a long column, probably more or less tortuous. It is heated below, and a tendency to equalization of temperature throughout exists through the means of a circulation; but the difficulties of circulation cause always a higher temperature at the bottom. After a time the bottom temperature exceeds the boiling temperature at the top, but the bottom water does not boil because the pressure is increased. At the depth of thirty-three feet the pressure is

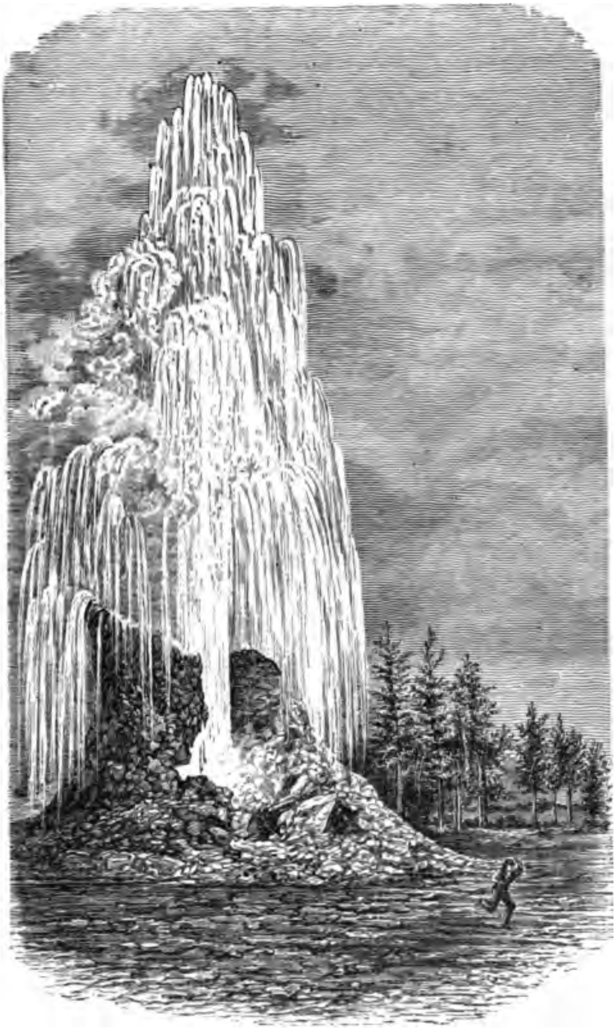


FIG. 60.—GIANT GEYSER IN ACTION. UPPER GEYSER BASIN, FIRE HOLE RIVER, YELLOWSTONE NATIONAL PARK. (Peale.)

two atmospheres, and the boiling temperature 250°. But by-and-by the increase of heat below brings the water to the boiling temperature; or in some cases a momentary relief of the pressure makes the existing temperature a boiling temperature. Then steam is instantly formed, and the column of water above is thrown out.

A somewhat simpler explanation is suggested by the well known behavior of water and steam when attempting to circulate through the same pipe, and by the analogous case of water and gas in one of the spouting wells of an oil district. Water simply accumulates in the geyser pipe upon the steam formed in the lower part by the bottom temperature. The steam for a time is subjected to compression, and the compression (condensation) increases with the continued development of steam. Finally, the elastic force becomes sufficient to lift the column of water. The

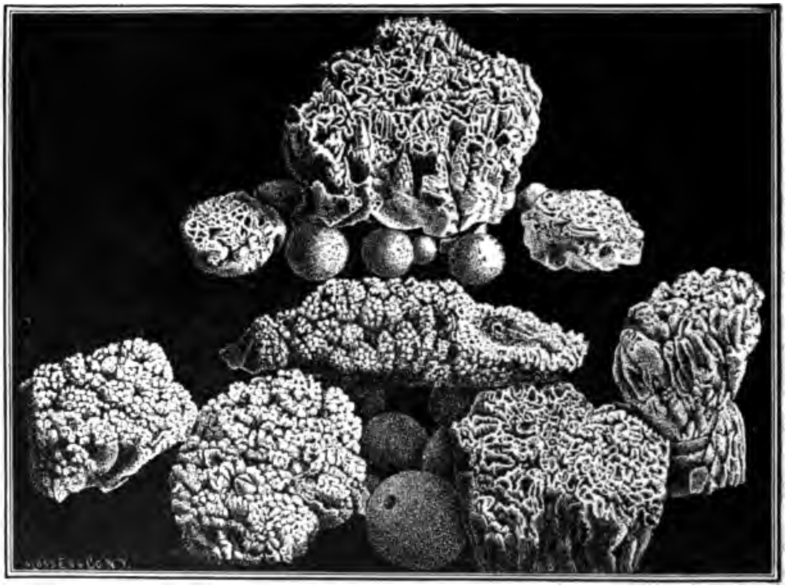


FIG. 61.—GEYSERITES. FROM UPPER AND LOWER FIRE HOLE BASIN. (Peale.)

commencement of escape now diminishes pressure, and a large volume of steam is instantly formed, which causes the violent action. The heavy thumps sometimes heard before and during the action are due to collapses of steam in contact with the water, and are strictly the same in principle as the sharper sounds frequently heard in the steam pipes employed for warming buildings.

EXERCISES.

The artesian well at the insane asylum, St. Louis, was 3,843½ feet deep, the temperature of the water 105°, and the mean annual temperature at the surface 55°; what is the rate of increase of temperature? The corresponding data at Charleston, S. C., were 1,250 feet, 87°, and 66°; what is the rate of increase? Make the calculation for any other well of which you can get the data. At what date will the temperature of July 1 be felt at the depth of twelve feet? If winter cold begins at Christmas, at what date will it penetrate through the ground to the bottom of a cellar five feet deep? Will the whole severity of the surface cold be felt at that depth? What should be the temperature of water from the bottom of a well one hundred feet deep at a spot where the annual mean is 40°? If the flow of water in this well comes from below, will its temperature be higher or lower than your calculation? How do we measure the temperature of the water in the bottom of an artesian well? Why can we not be sure the temperature there taken is the true temperature due to that depth? If the strata bored through have a steep dip, is the water likely to have come from a higher or a lower level? How would this affect the temperature? And would this wrong temperature affect your calculation of the rate of increase of temperature? What is the difference between an artesian well and a warm spring? If the temperature of a spring in central Arkansas is 100°, from what depth should the water rise? If the temperature of the Giant Geyser is 198°, what is the length of its funnel — taking no account of the elevation above the sea? Does this temperature of 198° indicate accurately the temperature at the bottom of the funnel? If not, why not? How does the discrepancy affect the result of your calculation? How many atmospheres of pressure at the depth resulting from your calculation? Try to ascertain at what temperature steam forms under such pressure. Suppose the temperature of the water is 240° and the pressure two atmospheres, will the water boil? Suppose now the pressure is suddenly diminished to one and a half atmospheres, what would happen? Why do warm springs deposit calcareous matter, and geysers silicious matter? Is the silicious matter the cause of the geyser mode of outflow?

STUDY XXIII. — *Volcanoes.*

We have ascertained, from observations made, that the internal temperature of the earth rises as we descend below the zone of uniform temperature, and to this fact we have not hesitated to ascribe the heat of thermal waters. We have no reason to doubt that the heat continues to rise beyond the possibility of the existence of water, and even till the temperature is sufficiently high to fuse mineral substances. This is an inference; but it is easy to subject it to the test of observation. Visitors to Naples, in Italy, tell us that in the immediate vicinity rises a mountain 4,000 feet above the bay, which is seen frequently to emit a volume of steam and smoke, as if its summit were a chimney, and a great fire were nursed within the mountain. This is Vesuvius. They tell us that the surface of the mountain is completely covered with ragged masses and scraps of rocks quite unlike any with which we are familiar, being dark, compact, fine, often glassy, in many cases coarsely cellular and light, and having much the appearance of slags from iron and copper furnaces. We may easily ascertain from the testimony of eye-witnesses that these slags have been ejected, in a molten state, from the chimney of the mountain, and that sometimes copious streams of molten matter have burst through fissures and flowed down the mountain side. These outflows are accompanied by volumes of aqueous vapor and gases and acid fumes, which rise in a vertical column through the *crater* to the height of several thousand feet — in 1779, ten thousand feet, according to Sir William Hamilton. Accompanying these are stones and ashes, sometimes in great abundance. The aqueous vapors condense in the upper air and form clouds, illuminated by the glowing lava and by the lightnings generated in the bosom of the vapor. Torrents of rain sometimes descend, converting the ashes into mud, and burying the surface of the earth for many miles around. There are records, indeed, of very destructive eruptions. One which occurred in the year 79 buried three cities — Pompeii, Herculaneum, and Stabiæ — and the work of excavating them is now in progress (Fig. 63).

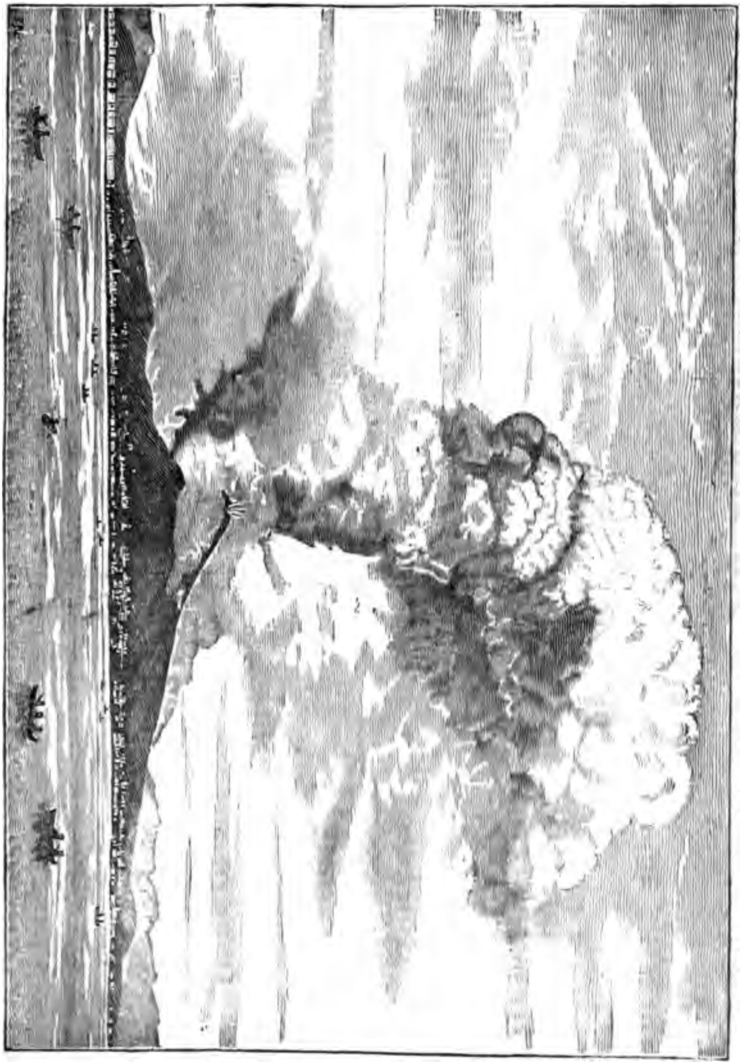


FIG. [illegible].—MT. VESUVIUS AND THE BAY OF NAPLES. (Palmieri.)

Vesuvius and Ætna are the two classical volcanoes of Europe; but many other evidences of the existence of internal fires are revealed in the volcanic activities of the Lipari Islands, in the *fumaroles* and *solfataras* of the volcanic districts, and in the occasional outburst of a volcanic island from the bottom of the Mediterranean. A *fumarole* is an escape of steam from the ground. When accompanied by sulphur vapors and other gases it is a *solfatara.* Fumaroles are numerous in the Yellowstone National Park, as also in most volcanic regions.

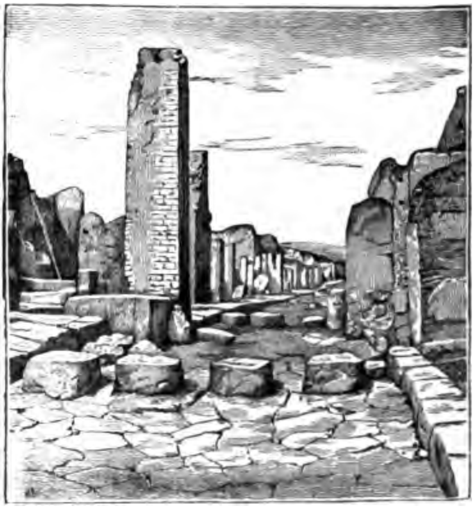


FIG. 63.—THE EXCAVATION OF POMPEII, BURIED IN AN ERUPTION OF VESUVIUS. Via Stabiæ, new quarter. (Photograph.)

Let us listen to a statement of what occurred on Ætna in 1865. This volcano, according to the government survey, is 10,868 feet high, and its sides slope at an angle of six to eight degrees. Its crater is a vast abyss, nearly 1,000 feet deep, and two or three miles in circumference. Sometimes it is nearly full of lava; at other times it appears to be bottomless. In July, 1863, after a series of convulsive movements, a fissure opened on the south side of the loftiest cone, and molten matter began slowly to issue and descend. Masses of lava and ashes were at the same time ejected from the mouth of the crater. For eighteen months the mountain threatened some ulterior convulsion. Molten lava rose in the crater and illuminated the skies. Evidently it pressed with enormous force against its walls, and these were continually weakened by melting away. At length, on the night of the 30th of January, 1865, the walls yielded, and a rent opened a mile and a half in length on the north of Monte Frumento, one of the secondary cones rising on the slope of Ætna.

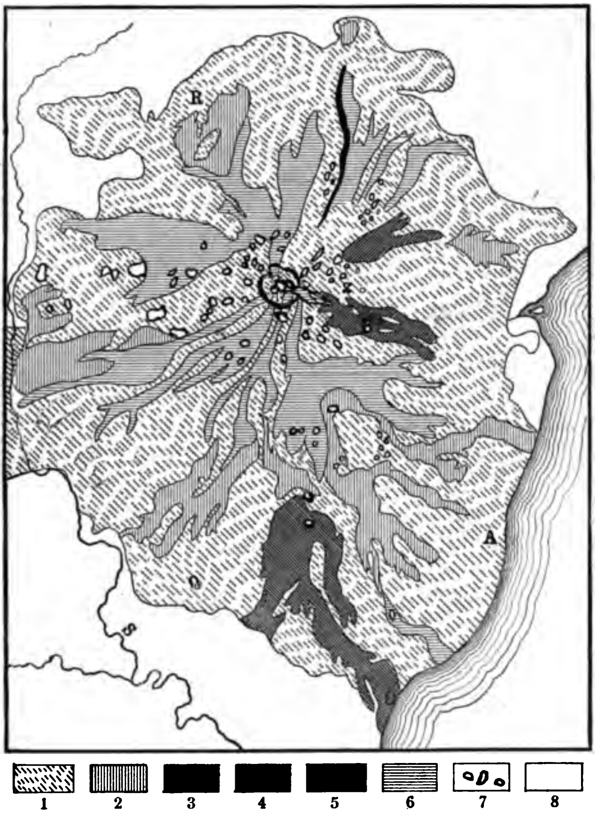


Fig. 64 —Map of Ætna and its Eruptions. (After S. von Waltershausen.)
1, Ancient Lava; 2, Lavas of the Middle Ages; 3, Lava of 1669; 4. Lavas of 1852 and 1865; 5, Lava of 1879; 6, Recent Lavas; 7, Cones and Craters; 8, Non-Volcanic Rocks. A, Aci Reale; B, Val del Bove; C, Catania; R, Randazzo; S, River Simeto.

From this molten lava issued for some hours, when communication with the interior supplies seems to have been obstructed. On the following day, new eruptions from the fissure took place, and six principal cones, formed of ejected matter, were raised. These gradually blended together, absorbing smaller cones, until a height of nearly 300 feet had been reached. The liquid lava issued from the lower craters, while the upper belched forth only stones and ashes. In two months the cone nearest to Frumento seemed to have become choked up, and only emitted sulphurous and hydrochloric vapors. The cone next lower continued to eject periodically, and with loud explosions, volumes of vapor, ashes, and stones; while the lowest cones continued to rumble and discharge molten matter. By degrees the violence of the action abated. At first the erupted matter rose 5,500 to 5,800 feet; then it fell to 300, and gradually ceased to escape.

During the first six days, the amount of matter escaping from the fissure, according to Sylvestri, was about 117 cubic yards a second — equivalent to a volume twice the size of the Seine at low water. Near the outlet it flowed twenty feet a minute; lower down, spreading over a wider surface, its speed was one and a half to six feet a minute. On the second of February the principal stream, now 900 to 1,650 feet broad and forty-nine feet deep, reached an escarpment three miles from the fissure, over which it plunged, a cataract of fire, into the gorge below. This spectacle was ended in a few days by the wearing down of the ledge and the filling of the ravine to the depth of 160 feet. From this the river of fire continued, and by the middle of February it was more than six miles long, well incrusted with cooled lava, and making but slow progress. Farm houses were swept away, and pastures and cultivated grounds were buried beneath slowly hardening rock. Entering the ancient forest, it swept down 100,000 to 130,000 trees, and the burning trunks floated along upon the moving stream. Some months after the commencement of the eruption, the interior of the stream of lava was still incandescent and moving. Continually the crust was burst by the pressure from behind; new rills would start and freeze, and fragments of the crust became implanted in the new rock, so that the exterior was roughened by innumerable sharp edged projections.

Fearful as was this eruption, it was insignificant compared with former ones. Since this date the mountain has been quiet; but during twenty centuries, seventy-eight eruptions have been recorded — the first in the seventh century B.C., in the time of Pythagoras. (See Fig. 64.) In some of them the flows of lava have been more than fifteen miles in length, and have covered areas of more than forty square miles (eruption of 1669), which were once in a perfect state of cultivation, and dotted over with towns and villages. The evidences are seen in the lava patches which still rest on the mountain slopes. In 1669 a stream of lava poured over the walls of Catania, sixty feet in height, and overwhelmed a part of the city. In 1693 an earthquake accompanied, which destroyed 60,000 to 100,000 inhabitants, of whom 18,000 were Catanians. In 1755 a flood of water, estimated at 16,000,000 cubic feet, descended the Val del Bove, carrying all before it. In former days, thousands of other lava flows and cones of ashes have added their contributions to the mass of the volcano, so that there is no spot which has not, sooner or later, been covered by the depositions. In fact, the evidence is that the total bulk of Ætna, from summit to base, down even to the lowest submarine depths, is nothing but the product of successive eruptions of molten lava, ashes and cinders.

From all observations made, it appears that the usual tenor of events attending an eruption of Ætna is as follows: Earthquakes are the premonitory symptoms; loud explosions are heard; rifts open in the side of the mountain; smoke, sand, ashes and scoriæ are discharged; the action localizes itself in one or more craters; cinders are thrown out, and accumulate around the crater in a conical form; ultimately, lava rises through the new cone, frequently breaking down one side of it, where there is least resistance, and flowing over the surrounding country. Then the eruption is at an end.

✓ Could we, with Captain Dutton, visit Hawaii, we should find the conditions varied, but essentially the same. This island is composed mainly of three volcanic mountains, Loa, Kéa, and Hualálai [give European sounds to the vowels] 7,822 feet high. Mauna Loa is 13,760 feet in height, and has, besides its summit crater, another one, Kilauéa, 3,970 feet above the sea level. This is a type of vent so unlike ordinary craters that Dutton proposes for it the new name *caldera.* The eruptions of Loa are quiet. The first indication is a light sent from the crater to the clouds. The liquid lava rises in the crater; sometimes it overflows, but generally a fissure opens on the side, and the lava pours forth, accompanied by ejections of stones, cinders, and ashes. The stream of lava has been known to flow sixty miles,

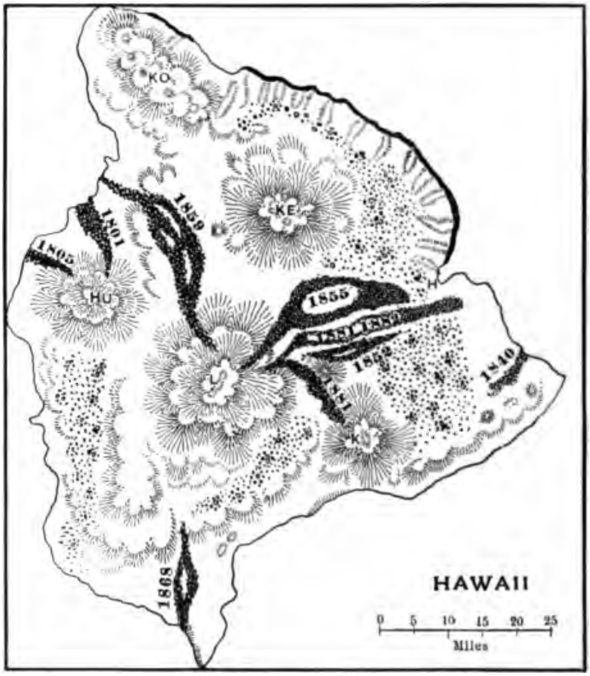


FIG. 65.—MAP OF HAWAII, SHOWING LAVA FLOWS. (Dutton.) *H*, Hilo; *H U*, Hualálai; *K*, Kilauéa; *K E*, Mauna Kea; *K O*, Kohala Mts. *L*, Mauna Loa.

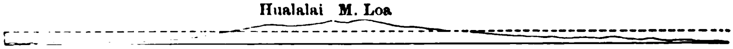


FIG. 66.—PROFILE OF HAWAII THROUGH HUALÁLAI AND MAUNA LOA, FROM N. W. TO S. E. Distance 30 miles. Section extends 18,000 ft. below sea level. (Dutton.)

and at times it has reached the sea. Lava streams of various dates are shown in Fig. 65. The eruptions at the summit crater are not generally accompanied by disturbances in Kilauéa. The converse is equally true. Kilauéa is a crater or caldera 16,000 feet long, seven and one-half miles in circuit, nearly four square miles in area, and 600 feet deep. The floor is of cooled lava, with one or more pits of molten lava continually in a state of agitation, and at times overflowing the brim and flooding the solid floor. Mauna Kea seems to be extinct. On the island of Maui, the volcano Haleakala is 10,217 feet high, with a crater 2,000 feet deep; and lava-flooded valleys one to two miles wide lead from it toward the sea.

The red sunsets of 1883 and 1884 are well remembered by all. It seems, at first view, very far-fetched to assume any connection between them and volcanic activities; but the opinion prevails very generally that they were caused by the fine ashes ejected on the 26th, 27th, and 28th of August, 1883, from a volcano on a small island lying in the Strait of Sunda, and commonly known as Kra-kat′oa. There were three volcanic summits on the island. The northern and lowest, Perboewatan, began to be active in May, after a rest of two centuries; the middle summit, Danan, was the seat of the great eruption of 1883, while the southern and highest summit, Ra-ka′ta, eight hundred and twenty-two metres, did not suffer. The eruption was accompanied by several terrific explosions, the greatest of which occurred at five minutes past 10 A.M., August 27, Batavia time. These air shocks travelled no less than three and one-fourth times around the earth. The sounds were heard over an area whose radius is 30°, or 3,333 kilometres, or whose diameter would reach from the Canary Islands to Jerusalem, and from Novaya Zemlia to the middle of the Soudan. The matter ejected is estimated at eighteen cubic kilometres; and within a circle of fifteen kilometres' radius the thickness of the layers deposited was twenty to forty metres —at the base of the mountain, sixty to eighty metres. The finer ashes fell 1,200 kilometres away, and the finest seem to have floated for months in the upper air. The steam-cloud was seen to rise 11,000 metres. The high southern peak was split through the middle, and the northern half, together with the other two mountains, sank out of sight. The soundings over it are now 200 to 300 metres. The size of the island was formerly thirty-three and one-half square kilometres; of this only ten square kilometres remain, but the volcanic depositions have added five square kilometres.

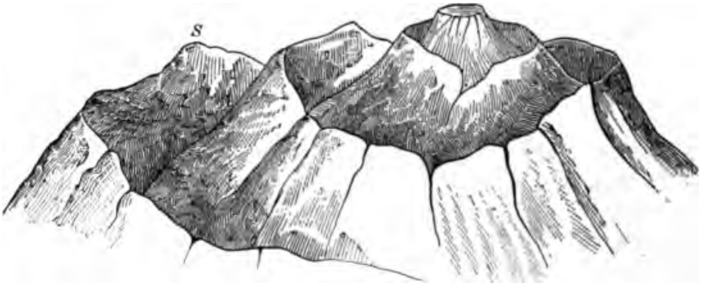


Fig. 67.—Form of the Summit of Vesuvius, in 1756, Showing Four Craters. (Scrope.)

The explosive sounds, the atmospheric shocks, and the great sea waves which destroyed more than 35,000 lives, are believed to be due to the falling in of the crater at successive intervals. This is a common incident of volcanic eruptions. The present crater of Vesuvius rises within a much larger crater, Somma, which resulted from the engulfment of a former crater during an eruption. In 1756 the summit presented the appearance shown in Fig. 67. Here were the remains of four craters, one within another. The phenomena of the Sundanese volcanoes illustrate the same thing, as shown in Figs. 68 and 69. This is

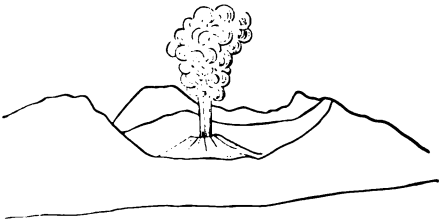


Fig. 68.—Triple Crater of the Tjoendoeng Volcano, Sumatra. (Hochstetter.)

explained by Hochstetter on the supposition of a vast excavation in the mountain, as shown in Fig. 70. By-and-by the arch becomes too weak to support its weight, and, falling into the abyss, leaves the circle of breakage to contribute the rim of a new and larger crater, as shown in Fig. 71. Then, after a period of quiescence, the liquid pool freezes over, and a new and small crater, on occasion of subsequent activity, begins to grow in the centre.

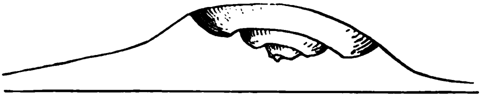


FIG. 69.—QUADRUPLE CRATER OF MERAPI (SUMATRA). (Hochstetter.)

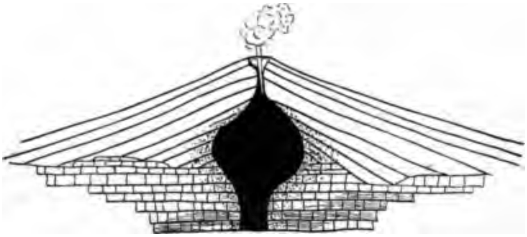


FIG. 70.—VOLCANIC CONE, WITH INTERIOR MELTED AWAY. (Hochstetter.)

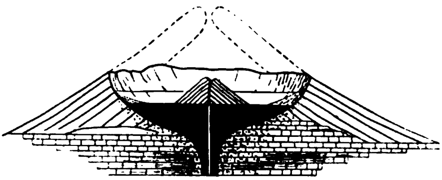


FIG. 71.—VOLCANIC CONE, AFTER THE FALLING-IN OF THE CRATER. (Hochstetter.)

Visitors to California and Oregon are greatly interested in the graceful forms of the volcanic peaks of the Sierra Nevada and Cascade ranges. Most admired of all is Mt. Shasta, rising a solitary and shapely cone 14,440 feet above the sea (Whitney). It has ceased to be active, but the evidences of great former activity appear in enormous sheets of volcanic material covering the country around. The fires of Mt. Hood, in Oregon, appear to be dying out, only moderate heat and vapors escaping to the top. But in times past it has covered many hundred square miles with its ejections. The Columbia River has cut through these in a chasm 4,000 feet deep. Mt. Ranier, in the same range, is 14,444 feet high. Its snow-white summit presents a magnificent spectacle from Seattle, seventy miles distant, on Puget Sound.

In many portions of the trans-Mississippi region the evidences of former volcanic activity are abundant. The whole Nevada range, from Lassen's Peak to Shasta, is volcanic, and so is the Cascade range, further north. Numerous series of volcanic cones stretch along the western slope of the Sierra. Near Mono Lake is a group extending far south, a view of which is shown in Fig. 72. This is a cluster of truncated cones of very steep sides, chiefly covered with ashes and other loose materials, and having numerous rocky projections rising from their broadly truncated tops. They reach the altitude of 9,200 and 9,300 feet above sea level.

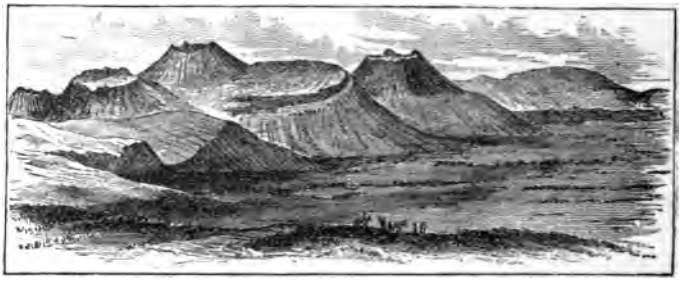


FIG. 72 —VOLCANIC CONES, NEAR MONO LAKE, CAL. (Whitney.)

Extinct volcanoes are known in many countries, but the most celebrated region is central France. Here hundreds of cones and enormous sheets of ejected material, worn, in later times, by the agencies of erosion, have given to a wide region an aspect entirely unique and full of interest to the geologist. Here is subjoined a view taken from the work of Poulett Scrope, who has studied and illustrated the region with more detail and thoroughness than any other investigator (Fig. 73).

EXERCISES.

What is the nature of the so-called "smoke" from volcanoes? Is there any "combustion" in a volcano? What is the source of the water which issues as steam? What evidence can you give that this is sea water? Have you ever heard of *mud* ejected from volcanoes? What analogy can you trace between volcanoes and geysers? Enumerate the principal lines and regions in which volcanoes abound. Enumerate volcanoes situated far inland. Give some account of any volcano not mentioned in the present study. What must be the effect of volcanic action on the internal heat of the earth? If the volcanic cone is formed of ejected materials, what is under the cone? Do you imagine any rocks of sedimentary origin could be there? Could granitic and other metamorphic rocks be there? (See Fig. 46, "trachyte" and "basalt.") Professor Whitney found masses of rose-colored granite on the tops of the cones shown in Fig. 72; how could they be accounted for? Why not consider them bowlders? Would it be surprising to see rounded stones ejected from a volcano? Should you see them, where and how would you suppose them rounded? Should they afterward be cemented together, what sort of a rock would be formed? Have you ever heard of such a rock as a fact? Can you suggest why the eruptions of Ætna and Vesuvius are attended by earthquakes, and those of Mauna Loa not? Does it appear that different volcanoes have an underground connection? Do

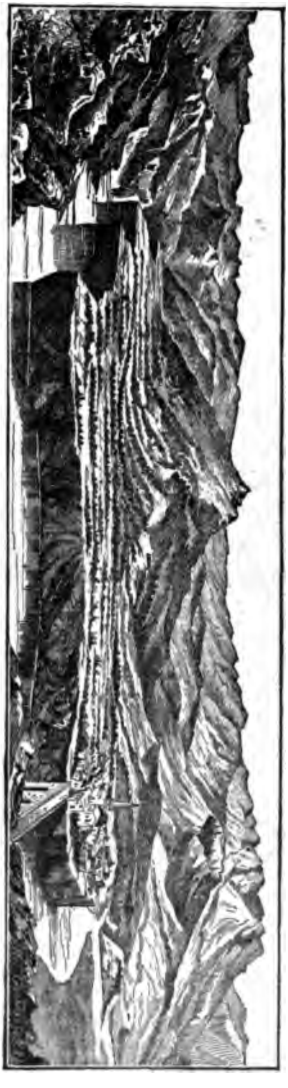


Fig. 73.—Volcanic Cone and Basaltic Lava, Current of Jaujac, Ardèche. (Scrope.)

the summit crater and Kilauéa sympathize together? Do Ætna and Vesuvius? Do Ætna and Stromboli? Assuming the two craters of Mauna Loa to be connected, how could lava stand in the summit crater, 9,000 feet higher than Kilauéa, without escaping at Kilauéa? Supposing the specific gravity of the lava two and eight-tenths, how many atmospheres of pressure would be felt at Kilauéa?

STUDY XXIV.—*Ancient Lavas.*

The traveller returning southward from a trip to Mt. Shasta may follow the broad valley of the Sacramento River. On his left rise the peaks of the Sierra Nevada, with the foot hills in the nearer distance. For a hundred miles, from Pitt River to Oroville, along the eastern side of the Sacramento, he traverses a broad plain of volcanic ashes, destitute of trees and almost destitute of herbage, and as yet hardly eroded into cañons. On nearing Bear Creek, more solid lava makes its appearance, and increases as he passes southward. This belt averages about seventy-five miles in width. The materials may be traced chiefly to the great centre of eruptive agency at and near Lassen's Peak, in the Sierra Nevada. The sheets of lava form a regular slope from the Peak to the Sacramento. Through this the more southern streams have sunken their channels five hundred to eight hundred feet deep. In some situations crater-bearing cones rise over eight hundred feet, and from these have issued a portion of the materials which flooded the valley. These were laid down on Cretaceous strata. Tuscan Springs, already mentioned (Fig. 57), are in this region. The section shows that the Cretaceous strata were somewhat tilted before the lava was poured out, and further tilted since that event. The conglomerate is not volcanic, and its presence implies the action of a transporting agent over the surface after the upheaval of the Cretaceous. To this is probably to be attributed the erosion of the strata. This section also shows a breakage of the strata and the escape of warm mineral waters.

Near the southern limit of this lava sheet, in the centre of

Butte county, the streams have cut quite through the lava into the underlying formations, giving rise to forms known as "table mountains." Here, underneath all, are exposed the auriferous slates, tilted up to a steep northeasterly dip, and containing intercalated beds of Carboniferous Limestone. On the upturned edges of these strata rest nearly horizontal Cretaceous sandstones, with a slight southwesterly dip. Above these are sandstones interstratified with shales containing leaves of Pliocene age. Upon these lie accumulations of volcanic ashes, scoriæ and breccia, and over all rests a heavy bed of basaltic lava. The section, Fig. 74, is taken across the general direction of the streams, and presents, therefore, cuts across a series of lava-topped belts, intervening between the streams.

The great auriferous region stretching to the south of this has also been the theatre of extensive lava displays. In El Dorado, Calaveras, and other counties are other table mountains, but in Tuolumne county, one hundred and fifty miles south, is *the* Table Mountain which has become so celebrated for its connection with mining operations and the discovery of fossil remains. Its mode of origin is not different from the origin of those in Butte county. The summit of the mountain is occupied by a heavy bed of basaltic lava one hundred and forty to one hundred and fifty

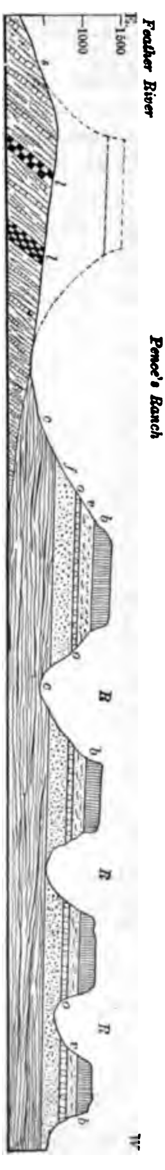


Fig. 74.—Section from East to West in Butte County, Cal., Eight Miles. Showing the Formation of Table Mountains. *s*, Auriferous Slates; *l*, *l*, Carboniferous Limestone Belts intercalated in the auriferous slate; *c*, Cretaceous Shales nearly horizontal; *f*, Tertiary Sandstones, with Vegetable Impressions; *e*, Band of Conglomerate above the Tertiary; *v*, *v*, Ashes and Volcanic Tufa; *b*, *b*, Hard Basaltic Lava, capping the hills and forming "table mountains"; *R*, *R*, *R*, Modern river channels; *b*, *b*, *b*, Direction of ancient river channel. (Adapted from Whitney.)

feet thick. Its width is about 1,700 feet. Underneath is a heavy deposit of detrital material very distinctly stratified and nearly horizontal, composed mostly of fine-grained sandstone or feebly coherent sand, interstratified in which are fine argillaceous shales and clays. With these are beds of gravelly materials strongly cohering together, and called "cement" by the miners. At the bottom is the "pay gravel" or the "channel," a body of coarse gravel exactly like that seen in the bed of an ordinary river, and here gold-bearing. The entire thickness of the detrital beds directly under the centre of the lava is, in one locality, at least fully two hundred feet. But this thickness is much less at the edge of the deposit, owing to the rise of the underlying vertical auriferous slates on each side, as shown in the figure, forming what is known to the miners everywhere in California as the "rim rock." The rim rock rises here fully one hundred and fifty feet above the level of the "pay gravel." The latter, occupying the lowest position, is four or five feet thick, and in this place is eighty feet wide. To reach this gravel, tunnels are run in through the rim rock, as shown on the right, or sometimes through the cement. When the channel is reached, it is "drifted" on, the miners following the paying streaks, or lines of auriferous gravel, up and down in the bed of the ancient water-course.

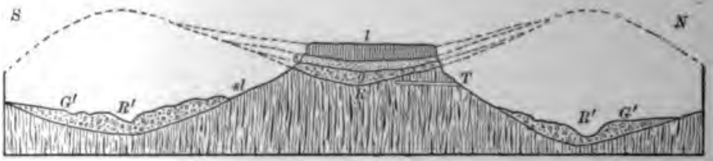


FIG. 75.—TABLE MOUNTAIN IN TUOLUMNE COUNTY, CAL., AT THE BUCKEYE TUNNEL. *l*, Lava forming the table; *s*, Sandstone under the lava; *g*, Gravel; *sl*, Slate; *R*, Old river bed; *R'*, the modern river bed; *T*, Tunnel through the "rim slate" to the "deep placers"; *G'*, Modern Gravel and "shallow placers." The dotted lines indicate the probable configuration of the surface when the lava was erupted. (Adapted from Whitney.)

What else but a water-course could this trough have been? What else but a bed of river gravel, this which lies strewn along the bottom of the channel here excavated in the slates? There was, in a former time, a stream flowing from the east over the outcropping edges of the auriferous slates, and strewing its bed with gravel from the quartz veins in the slate. On each side was a sufficient rise in the surface to bound a river valley as indicated by the dotted lines. By some change in the mode of action, the sands were laid down over the gravel. Then came an enormous flow of lava from the vents of the Sierra, occupying the entire bed of the stream and partly filling the valley. The stream displaced wore a new channel along the border of the lava bed. It wore the bounding slope away, and sunk a modern channel deeper than the old one, leaving the lava to cap an elevation in the very place where once was the valley. The modern stream brings auriferous gravel like the ancient one. These are the "shallow placers"; the other gravels are the deep placers.

The table mountains of Butte county admit of a similar explanation. But the direction of the modern streams in this region crosses the course of the ancient ones. Many impressive examples of a similar nature occur in central France, some of which are illustrated in Fig. 76.

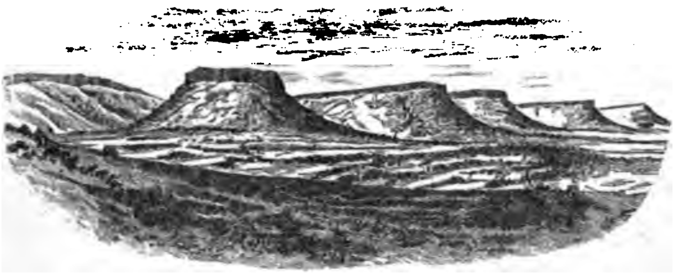


FIG. 76.—BASALTIC PLATEAUX OF THE COIRON, ARDÈCHE. (Scrope.)

Many remains of mammalian quadrupeds have been found in the deep placers of California. They embrace mastodon, rhinoceros, and extinct species of horse, species of hippopotamus and camel related to the living species, and, finally, several human bones, including an imperfect skull. The question remains as to the precise age of these auriferous gravels; but it appears, at least, that enormous floods of lava have been poured out over the plains and valleys of the western slope of the Sierra since man became an inhabitant of California.

It is not necessary to enter further into particulars. Not only has so large a part of California been inundated by sheets of molten lava, but even larger areas have been covered in other regions of our Pacific slope. According to Leconte, "the great lava flood of the Northwest covers an area of 150,000 to 200,000 square miles, and is 3,000 to 4,000 feet thick in its thickest part, where cut through by the Columbia River at the 'cascades.'" In another place, at least seventy miles distant, where cut into 2,500 feet deep by the Des Chutes River, at least thirty successive sheets may be counted. Another great lava flood, according to Gilbert, covers 25,000 square miles of Arizona, and is 3,000 feet thick in its thickest portions. In New Mexico, according to Captain Dutton, the San Mateo Mountains are a volcanic pile 11,380 feet high, carved into numerous spurs by magnificent gorges. From this centre the lavas reach out for forty-five miles to the north-north-east, and in other directions for eighteen to thirty miles. The lava forms a superficial sheet over each mesa or table, ranging in thickness from fifty to two hundred feet. Many of the vents scattered around the flanks of Mt. Taylor can be easily identified. The "necks" or "chimneys" which are left standing in the valley plains beyond the farthest verge of the lava-capped mesas are among the most striking features of the country. One is nearly 2,000 feet high.

Those who have visited the "Giant's Causeway" or Fingal's Cave have seen other great masses of rocky material, having all the essential characters of lava erupted from volcanoes. These are, indeed, the results of igneous eruption, though there be no mountain, and no discovered point where the outflow took place. It escaped through fissures. One travelling along the highway in the valley of the Connecticut south of Hartford may notice at intervals an abrupt ridge running in a straight line across the alluvial meadows. Examination discloses the existence of a vertical wall of rock rising from the underlying sandstone and rising out of it. The nature of the rock is essentially lava-like. It seems to have been lava which rose in a molten state through a fissure in the stratified sandstones beneath. This is called a dike. Dikes of melaphyr are shown in Fig. 46, and an actual group of trachytic dikes in Fig. 83. In the Meriden Mountains, not far away, we discover masses of ancient lava which have risen through such dikes. The outflows continue along the valley of the Connecticut to New Haven, where prominent headlands are known as "East Rock" and "West Rock." Travelling up the Hudson, our attention is arrested by the "Palisades," which are only another mass of ancient lava erupted, like the Giant's Causeway, without the intervention of a volcanic mountain. In Fig. 46 is shown a basaltic outflow, intended to illustrate basaltic formations in various parts of the world. Basaltic

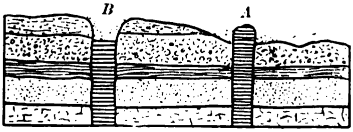


FIG. 77.—DIKES. (See also Fig. 83.) A is harder than the contiguous strata, and B is softer.

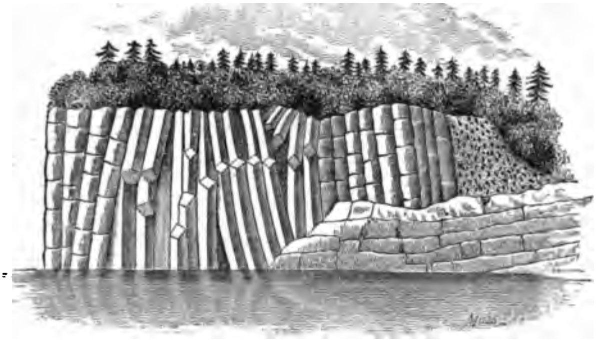


FIG. 78.—BASALTIC COLUMNS ON SEDIMENTARY ROCK. HAVING THE COOLING SURFACE HORIZONTAL. (After Owen.)

outflows often assume columnar form, and we observe that the axis of the column is always at right angles with the cooling surface. In Fig. 78 the columns are vertical because the cooling surfaces were horizontal. In Fig. 79, which shows a dike of basalt, the columns are horizontal because the cooling surfaces were vertical. If we take a mass of wet starch and allow it to cool rapidly, a similar prismatic structure is developed, as is seen in the laundry starch of the markets. The form is perhaps due to general shrinkage. Possibly ancient lavas, while cooling, developed a similar structure from the same cause.

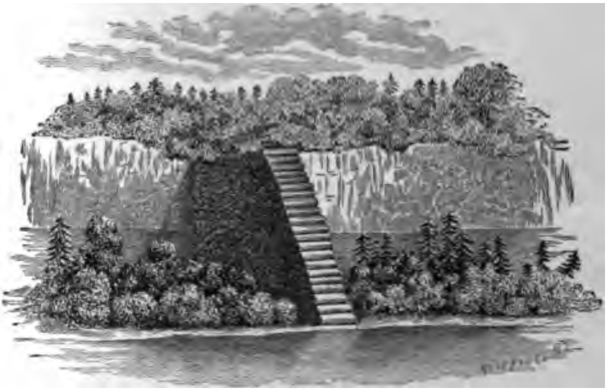


FIG. 79.—BASALTIC PRISMS FORMED IN A DIKE. HAVING THE COOLING SURFACES VERTICAL. (After Owen.)

At Keweenaw Point, or its vicinity, on the south shore of Lake Superior, are the evidences of an enormous outflow of molten lava, which issued in very remote times, and spread out in numerous sheets, alternating with sheets of pebbles, which have become cemented into conglomerate. In this occurs the native copper. Much of this lava presents the character of *amygdaloid*, Fig. 80. When cooling, it abound-

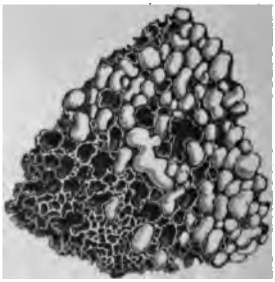


FIG. 80.—SCORIACEOUS LAVA, IN PART CONVERTED INTO AMYGDALOID. CENTRAL FRANCE. (Lyell.)

ed in bubbles of gases, and became exceedingly vesicular, like some scoriæ of modern volcanoes. After the gases escaped, the cavities were filled with various minerals, infiltrated in a state of solution. The rock receives its name from the *almond*-shaped inclusions, and it retains the name even after the minerals have dissolved out.

The Geological Survey of Italy has lately published sections of the island of Elba, which show a mass of Eocene strata interpenetrated and interbedded in an extraordinary manner, with dikes and intrusions of porphyry, which materially swell the mass of the island. Fig. 81 is one of the sections.

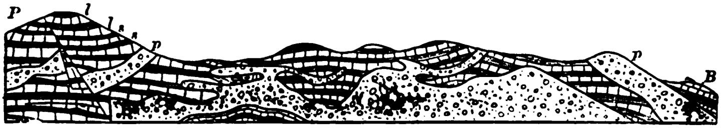


FIG. 81.—SECTION ON THE WEST PART OF THE ISLAND OF ELBA, 900 METRES. *P*, Cape Poro; *B*, Bardella Point; *l*, Limestone; *s*, Schists; *p*, Porphyry. (Geol. Surv. Italy.)

Mr. G. K. Gilbert, in a report on the Henry Mountains, of Utah, has made us acquainted with an extreme development of *intrusive* lavas; that is, igneous rocks forced into the seams separating sedimentary strata (Fig. 82). Such cases have long been known, and Fig. 46 shows porphyry so intruded. But in the Henry and other western mountains, the force and volume of the intrusion have been such as to actually lift the overlying masses of strata, as here illustrated. Subsequently, erosions have in some cases worn away the overlying strata, and the included porphyritic trachyte is gnawed into

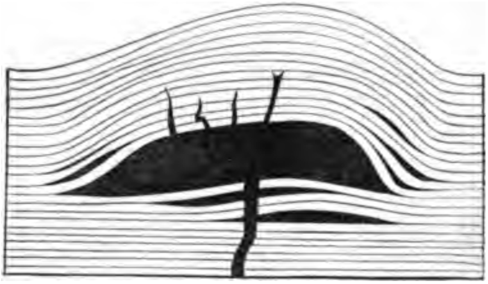


FIG. 82.—IDEAL CROSS-SECTION OF A "LACCOLITE," WITH ACCOMPANYING SHEETS AND DIKES. (Gilbert.)

many fantastic shapes. The crest of Mt. Holmes (Fig. 83) affords an excellent illustration of dikes.

Recurring again to Fig. 46, we notice a representation of a vein of granite injected into another mass of granite. It is the general opinion that granite, in vein form, must have cooled from igneous fusion; but there are some who think otherwise. You see, also, that rocks of the *eruptive* class include also porphyries and other varieties somewhat different from common lavas.

The observations which we have made in the last three studies show:

1. That the internal temperature of the earth increases as we penetrate downward. There is consequently, and necessarily, a constant *transfer* of heat from the deeper and warmer parts to the shallower and cooler parts. In other words there is a continual flow of heat from the interior to the surface, and a final radiation and wastage of it from the surface. Thus the simple fact of internal increase of heat proves that *the earth is now cooling.*

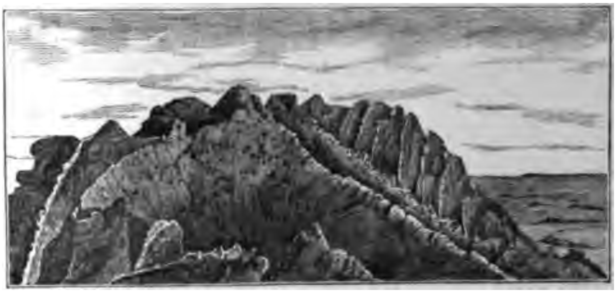


FIG. 83.—THE CREST OF MT. HOLMES, UTAH. (Gilbert.)

2. The numerous evidences of more highly heated conditions at the surface in ages past are proof that the *cooling process has been long going on.* Our earth must therefore be contemplated as *a cooling body.* Many of the most important events in its physical history are known to have resulted as incidents of cooling. The fact of cooling has been a determinative principle in

terrestrial progress. It has had something to do with the earth's physical vicissitudes and resultant forms. Through these it has necessarily exerted conditioning influences on the organic beings which have populated its surface.

From what former high temperature has the cooling proceeded? Most of those who speculate on this question agree that the whole earth was once in a state of igneous fluidity. Not discovering any reason to conclude that even this was the starting point of the process of cooling, they carry the history of terrestrial matter back to a state of molten mist floating in a gaseous medium.

EXERCISES.

What is the evidence of the tilting of the cretaceous strata at Tuscan Springs, before the lava was poured out? What is the proof of a subsequent tilting? Which way do the strata dip at Tuscan Springs? Can you draw a diagram indicating the termination of the Cretaceous strata at a higher level than at the springs? What is the evidence of the existence of such higher outcrop? How does the water become warmed? How does it obtain its mineral properties? How can you reconcile the northeasterly dip of the auriferous slates with the fact that the Sierra lies in that direction? How can the Cretaceous sandstones over them be nearly horizontal? Can you explain why they dip slightly in the opposite direction? What is the source of the "pay gravel" in the deep placers? By what streams transported? What is the difference between these and the shallow placers? After a lava stream displaced the old river, how came a new channel into existence on each side of the lava stream? What is the evidence that the ancient streams of Butte county ran across the direction of the modern streams? Have you ever seen a deposit of volcanic rock? What locality of volcanic rocks is nearest to this place? Could vesicular lavas form if the cooling took place under great pressure? Why do you answer thus? Do you think the trachyte of the Henry Mountains is vesicular or compact? Why do you answer thus? Are amygdaloids of sedimentary origin or not? Are they metamorphic? Do they denote any particular kind of eruptive rock? Does the designation relate to composition or to structure?

STUDY XXV.—*Mountain Phenomena.*

Let us trace somewhat farther the results of disturbances of the earth's crust. If we turn back to Fig. 38, we notice that the disturbance of the strata results in an elevation of surface having the appearance of a mountain. You have already recognized here the indications of an upheaval of the granite mass which seems to burst through the beds of gneiss once overlying. This figure may be taken as a general section across the Laurentian mountains of Canada or the Adirondacks of New York. The Humboldt, Wahsatch and many other mountains exhibit a similar structure. But we are not certain the central mass becomes exposed to view in consequence of protruding through the overlying rocks. Perhaps the gneisses or other strata continued to conceal the granite or other central core, after the upheaval, and have been subsequently worn away. It is also quite supposable that a granite summit was originally uplifted above the sea level, and the gneisses when forming as sediments never covered that portion of the granite now exposed to view. It requires sometimes much study to determine in which way it happened that the central mass, whether granitic or not, stands uncovered by later strata. In the case of the Laurentian mountains and the Adirondacks, the third explanation is held to be the true one.

The section through Tennessee, Fig. 33, which we have used to illustrate erosion, is also a good illustration of two kinds of mountain structure. At the east we see the massive strata of the Unaka ranges standing at a very high inclination, and rising to an average altitude of 5,000 feet, along the entire eastern border of the state. We find at least twenty-two summits which exceed 6,000 feet in altitude. These rocks, according to Safford, are chiefly thick beds of sandstones and conglomerates of the Primordial Group (see Fig. 39), partly in a metamorphic state — that is, changed to gneisses and schists. There are two, and for part of the distance, three parallel ranges constituting the Unaka chain, and this is a part of the great Appalachian chain, stretching from New England to central Alabama. The strata of the Unaka ranges are seen to be *monoclinal* — having the dips all in the same direction. This may be distinguished from the *anticlinal* structure.

Recurring again to the section through Tennessee, we observe a fine example of another class of mountains. The Cumberland table land stands at a mean elevation of 2,000 feet above sea level. It is a flat-topped mountain from fifty to seventy-five miles in width, and stretching from Georgia through Tennessee and Kentucky. It can indeed be traced through West Virginia and Pennsylvania into southern New York. It subsides in northeastern Alabama. As we inspect this east and west section through the table land, it becomes obvious that this is not a mountain mass which has been upheaved, but is a region of *relief*, resulting from vast erosions along its eastern and western sides. The contiguous valleys have been excavated. The strata, moreover, remain nearly horizontal. They have not been disturbed. They consist of rocks of Upper Carboniferous age. Lookout Mountain and Missionary Ridge, the sites of important battles, are *outliers* of this great table land. Mountains of relief are styled by Powell, "cameo mountains."

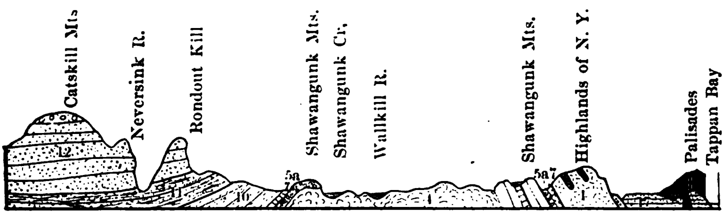


FIG. 84.—SECTION FROM THE CATSKILL MOUNTAINS TO THE HUDSON RIVER. (Mather.)

The Catskill Mountains present a similar structure (Fig. 84), consisting of nearly horizontal beds, but having a slight dip southwest, piled up two, three, or four thousand feet above sea level. They belong to the age of the Devonian. The Uinta Mountains are somewhat in the form of a table land; but they are not a proper table land, since upheaval as well as erosion has been concerned in the production of the salience. They are one hundred and fifty miles long and fifty broad. In Fig. 85 is presented an idealized section, from Powell, showing a mass of folded strata in the interior, over which passes a broad swell, which has been extensively eroded and flattened along the top. Actual observation has not extended below the level of *A B*. *C D* is the sea level, and *Y* is the bed of the Green River, which has been enabled to cut through the mountain, because it existed before the mountain, and the mountain slowly rose under it, as a log moves on a saw. The river, then, as Powell suggests, has sawed the mountain in two. The actual elevation of this fold was about

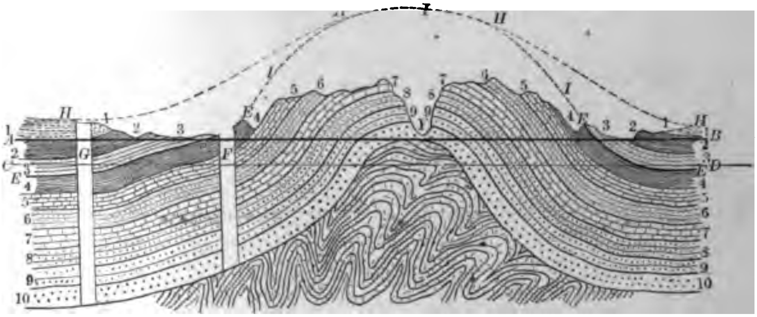


FIG. 85.—GENERALIZED SECTION THROUGH THE UINTA MOUNTAINS, FROM NORTH TO SOUTH. (Powell.)

30,000 feet. The mean depth of the degradation from the summit is three and a half miles, and as the area of the mountain proper is about 2,000 square miles, the total degradation is 7,000 cubic miles. The materials were deposited in the bottom of the ocean then contiguous. This took place during the earlier Eocene. On the north the sedimentation partly supplied from this source amounted to more than 6,000 feet, and in some parts to 8,000 feet. We thus get new illustrations of doctrines previously generalized.

From what we have already seen, it is apparent that different portions of the earth's crust have been subject to considerable vertical movements. These could hardly be conceived to take place without extensive fracturing of the strata. In fact, a reexamination of some of our sections, which are simply pictures from nature, will disclose the presence of fractures. In the section through Tennessee (Fig. 33) we find a break some distance east of the Cumberland table land. Notice that the strata on opposite sides dip in opposite directions, and do not correspond together. On the eastern border of the valley of East Tennessee is another break, and the strata on opposite sides have different inclinations, and do not correspond. Such an occurrence is called a *fault*, or *dislocation*. Many times the rocks on one side of the fault have been raised or lowered more or less from their original position, and sometimes considerable movements have taken place. Vast dislocations exist elsewhere in the Appalachians, and this is indicated in the diagram, Fig. 34. In several cases the downthrow amounts to 5,000 or 10,000 feet; and Lesley gives an account of a fault not less than 20,000 feet, bringing upper Devonian strata on one side opposite the lowest Cambrian on the other.

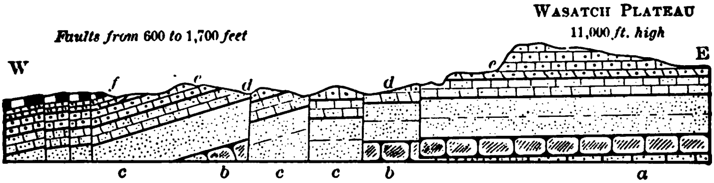


FIG. 86.—SECTION EAST AND WEST IN CENTRAL UTAH, SHOWING NUMEROUS FAULTS. *a*, Triassic; *b*, Jurassic; *c*, Cretaceous; *d*, Laramie; *e f*, Tertiary. (Dutton.)

Some of the grandest fractures and faultings known in the world occur in the Rocky Mountains and the regions farther west. The anticlinal of the Park Range of the Rocky Mountains was cleft down the axis, and the eastern half depressed 10,000 feet. Colorado Range was severed by an enormous southeast-northwest fault, which dropped the region of the Laramie Hills 6,000 or 7,000 feet lower than the southern continuation of the same ridge. The inclined easterly dipping Palæozoic and Meso-

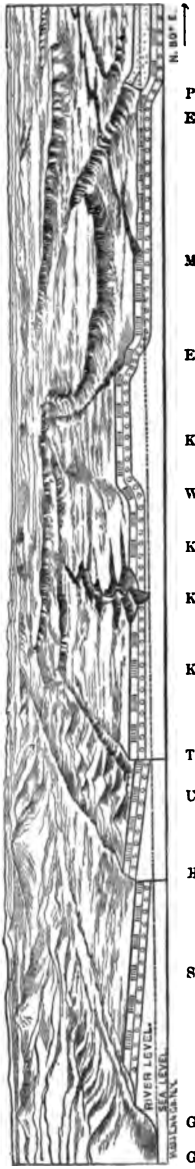


Fig. 87.—Section from West to East across the Plateaus North of the Grand Cañon, with Bird's-eye View of Terraces and Plateaus Above. (Powell.) Horizontal scale, 24 miles to the inch; vertical, 6 miles to the inch.

zoic rocks of the Wahsatch, in the region of the Cottonwood, rested against the abrupt, precipitous face of a granite cliff, of which 30,000 feet are now exposed (King). In Fig. 86 we have a section in central Utah, showing seven faults. The great fold of the Uinta Mountains produces, along some parts of its borders, so sharp a flexure that the strata are broken and faulted. A great fracture runs along the axis of the Sierra Nevada for 300 miles, accompanied by a dislocation of 3,000 to 10,000 feet. For a large part of this distance the eastern half of the split fold has sunken down to a level with the plain, while the western half remains elevated. The consequence is, that the mountain presents a gentle slope on the west, and a very precipitous one on the east. This appears, consequently, to be a mountain of a type different from any before distinctly mentioned. It is a monoclinal mountain, but the continuity of the strata is not interrupted by erosion, but by precipitation into the abyss. Similarly the Wahsatch range has been cleft by a fault at least 100 miles long, and the west half has sunken 40,000 feet (King). As the faulting process has had so much to do with the surface configuration of the plateau region of the West, we reproduce in Fig. 87, from Powell, a bird's-eye view of the great Colorado plateau north of the Grand Cañon shown in the sketch, Fig. 31. This will be convenient for reference in connection with other points of geological interest.

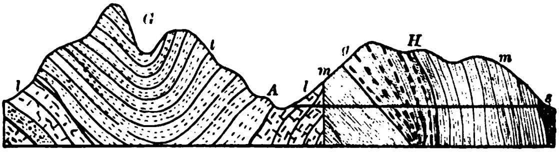


FIG. 88.—GRAYLOCK, A SYNCLINAL MOUNTAIN. (Emmons.) *G*, Graylock; *H*, Hoosac Mountain and Tunnel; *A*, North Adams; *l*, *l*, "Eolian Limestone" (Trenton); *t*, Talcoid Schist; *m*, Mica Schist; *g*, Gneiss; *s*, Steatite.

In Fig. 88 is shown another variety of mountain. This is a synclinal mountain, or one in which the dips of the strata are from opposite sides toward the centre of the mountain. Correspondingly, the contiguous valleys are anticlinal. This results from the more rapid erosion experienced along the exposed and, probably, fractured anticlinal crest. In consequence, the actual original crest has been lowered below the level of the valley, and the valley stands forth as an elevation. Thus a valley comes into existence where the mountain was, and a mountain remains where the valley was. Mt. Kearsarge, in New Hampshire (Fig. 89), is one of many illustrations. It is one of the various results of the combined action of upheaval and erosion.

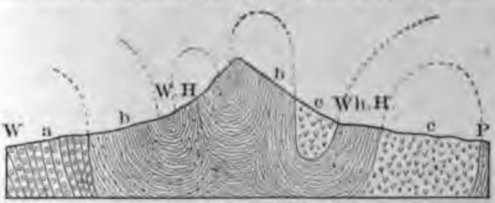


Fig. 89.—Section through Mt. Kearsarge, N. H., Showing Synclinal Structure. (C. H. Hitchcock.) W, Wilmot; W H, Wilmot House; Wh H, White House; P, Plumbago Pt.; *a*, Porphyritic Gneiss; *b*, Andalusite Mica Schist; *c*, Granite.

Fig. 90.—The Needles of Charmoz and the Mer de Glace, Switzerland. (Photograph.)

In Figs. 90 and 91 we have views of a type of mountains resulting from a vertical position of schistose rocks sharpened by weathering. These are the well known "needles" (*aiguilles*) of the Alpine ranges.

Now let us reduce to a systematic statement the various types of mountain structure to which our attention has been directed, whether in this study or preceding ones.

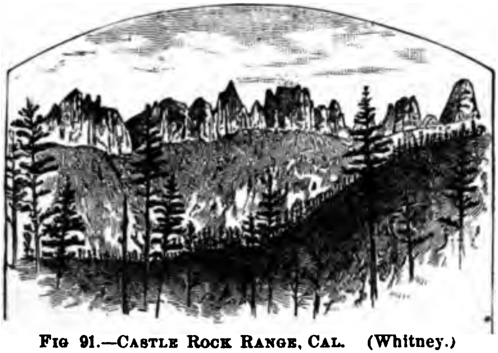


FIG 91.—CASTLE ROCK RANGE, CAL. (Whitney.)

TYPES OF MOUNTAIN STRUCTURE.

I. **Sedimentary.** The mountain mass composed of sedimentary rocks.
  1. UPHEAVAL, modified by subsequent denudation.
    (1) Anticlinal in origin and fundamental form.
      (*a*) Amphiclinal in actual form. Actual dips both ways.
        Rocky Mountain and Basin Ranges.
        (*α*) Central mass an antecedent exposure—primordial.
          Laurentian, Adirondac, Humboldt.
        (*β*) Central mass protruded, or revealed by denudation.
          Mill Mountain, Va., Piñon and Diamond ranges.
      (*b*) Monoclinal in actual form.
        (*α*) Resulting from denudation.
          Unaka Mountains, Tenn. and N. C.; Wolf Ridge, Va.
        (*β*) Resulting from faulting.
          Elk Mountains, Sierra Nevada, Wahsatch, many Basin ranges.
          Typical structure of Rocky Mountains. (Dutton.)
      (*c*) Orthoclinal, with the strata vertical (generally sharpened by erosion).
        Alpine "Needles." Castle Rock range, Cal.

(*d*) Hyperclinal, or "Fan Structure." Tilting carried beyond the vertical.
Mont Blanc, St. Gothard, San Luis, and Santa Lucia, Cal.
(2) Aclinal. Strata horizontal or nearly so.
(*a*) Bounded by monoclinals. Uinta mountains.
(*b*) Bounded by faults. Kaibab structure of Powell. (Runs into preceding.)
Common in the "Plateau Province."
2. RELIEF. Salience resulting from contiguous erosions.
(1) Tabular. Stratification horizontal.
Cumberland Mountains, Catskills, House Mountain, Va.
(2) Synclinal. Strata dipping into the mountain from opposite sides.
Mt. Kearsarge, N. H.; Becraft's Mountain, N. Y.; Mt. Eolus, Vt., Graylock, Mass., Mt. Everett, Mass.

II. **Eruptive.**
1. Material a deposition. Ejected, and brought down by gravity.
(1) Volcanic cones of ashes and cinders (generally with lava added).
Ætna, Vesuvius, Shasta, Mauna Loa.
(2) Volcanic sheets of ashes and cinders, subsequently eroded into saliences. Erupted depositions of Oregon. Peperino beds of Italy and elsewhere.
2. Outflow of molten matter forming sheets, subsequently eroded.
Lava mesas and mountains. Ridges near Silver City, Col.

III. **Combined.** Strata uplifted by intrusions beneath.
1. Turgescence of crust. Action producing fractures and an excess of dykes and veins. Island of Elba.
2. Laccolites. Action intrusive. Laccolites variously eroded.
Henry Mountains, Sierra Abajo, El Late, Navajo Mountain, Indian Creek, Wy.

EXERCISES.

When we find a region having granitic rocks at the surface, why are there no other rocks over the granite? Can you be certain of the reason why the granite is exposed? Suppose the granite is much higher than the nearest newer rocks, what then would you conclude? What, if the granite exposure is lower than neighboring rocks of later date? How do you know when rocks are of later date than the granite? Suppose we find a mountain without granite exposed at the summit, does it probably contain granite? In the section through Tennessee, Fig. 33, point out two types of mountain structure. In what direction do the rocks dip in the Unaka mountains? Is this a case of upheaval? Is this an anticlinal? How many branches or sides has an anticlinal? How many are seen in the Unakas? Which branch is present?

Where is the other? What other type of mountain in the Tennessee section? Is this also a case of upheaval? Is the Uinta Mountain strictly a table land? Has there been any upheaval there? How does this case differ from an ordinary anticlinal? How do we know that the Green River, which has cut through it, is older than the mountain? If the river flowing south had been obstructed by the mountain, where would the river have gone? Would it have been possible for other streams to cut the mountain in other directions? What is the extreme extent to which you could conceive the mountain cut up? How might a detached outlier or column have originated? How do we know the formations north of the Uinta were derived partly from the destruction of the Uinta? When several thousand feet of sediments accumulate on a sea bottom, do you think the bottom would tend to sink? Suppose some thousands of feet are removed from the Uinta mountains, do you think the unloading would cause the region to rise? Look at Fig. 87 and point out the faults. Show where there has been a downthrow. Show a structure somewhat similar to that of the Uinta Mountains. Point out valleys of erosion. Do the Uinkaret Mountains look like anticlinals? Does the Pine Valley Mountain? Where is the Grand Cañon in this view? Which way does it run? In what direction do these great faults run? Draw a diagram to explain how a synclinal mountain might originate.

STUDY XXVI.—*Mountain Formation.*

We now present, in Fig. 92, a remarkable section in the Appalachian region, worked out by Prof. J. L. Campbell. All the principal varieties of mountain structure are here shown. The strata are Cambrian, Silurian and Devonian, and the particular formations are indicated by numbers and letters corresponding with the general table of formations, Pt. II, ch. ii, §5. For the purpose of showing the relation of the different kinds of rocks to the work of erosion, the conglomerates are distinguished by coarse dots, sandstones by finer ones, shales by closely ruled lines, while limestones are blocked, and those of different periods otherwise distinguished. Here will be noticed two great faults. The mass between them, some four miles long, has been thrown down. The dotted lines indicate the former extension of strata. This section must be much studied. It is substantially a *real* section. Such bendings, altitudes and fractures are facts scientifically worked out.

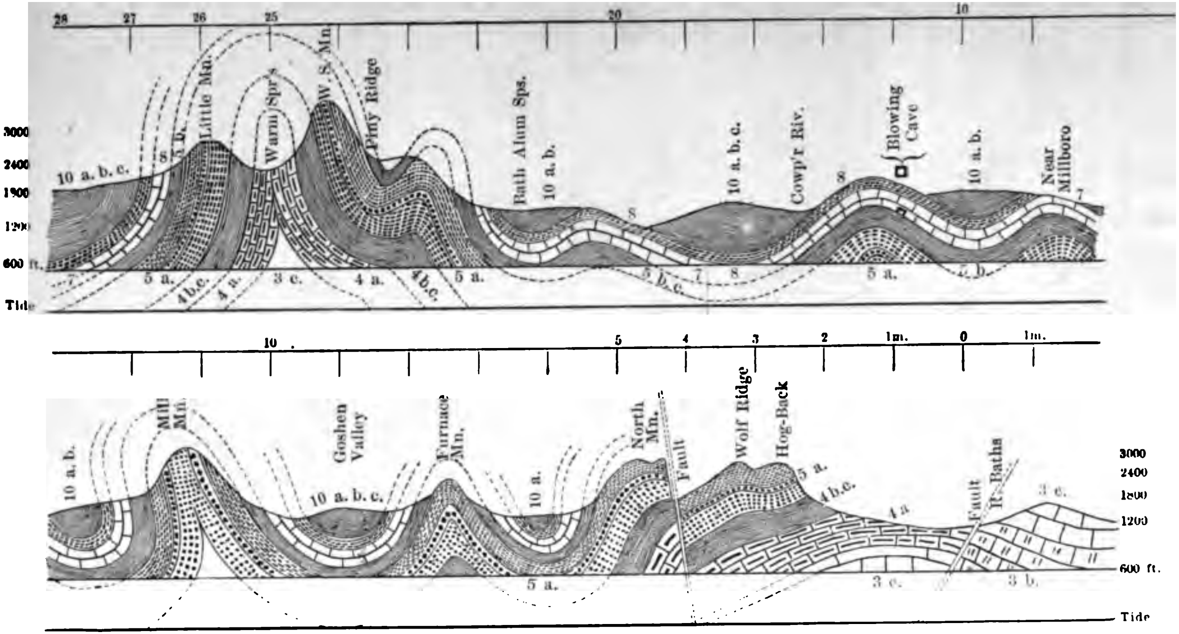


FIG. 92.—SECTION ACROSS A PORTION OF THE APPALACHIAN CHAIN IN ROCKBRIDGE AND BATH COUNTIES, VA. (J. L. Campbell.) The formations are designated by numbers taken from the table, p. 274.

A free glance at the foregoing section conveys the distinct impression that a pile of rocky sheets has been subjected to a folding process, and afterward extensively denuded. The folding process has in some places fractured the strata, and caused dislocations. It is quite possible that the faulting was a subsequent event. If this section were again flattened out, it would increase considerably in length. In the process of folding, therefore, the original length must have diminished. If this diagram were exact, and made to measure, we might lay a thread along one of the formations from end to end, and then measure the length of thread required, and thus ascertain the percentage of shortening in consequence of the folding. King estimated that ten per cent would not more than express the shortening of the strata folded up along the belt of the fortieth parallel. Some of the basin ranges have even undergone a longitudinal shrinkage of over ten per cent. (King, S. F. Emmons.) Claypole measured a section sixty-five miles long, across Huntington, Juniata and Perry counties, in Pennsylvania, and calculated the original length of the strata had been about one hundred miles, giving a shrinkage of thirty-five per cent. We may admit that this is perhaps an exaggerated estimate, and still feel certain that enormous shrinkage of a folded crust must take place.

A little reflection makes it apparent, also, that the movement of contraction and folding must be the result of pressure from without. A linear shortening, accompanied by folding, results from pressure from the ends. There must have been some enormous *lateral pressure* experienced by all parts of the folded crust. This conviction is strengthened by the appearance of the heavy-topped folds which resulted in the upheaval of the Alps of central Europe. The well known *fan structure* of the Alps is a remnant of the huge inflated folds, whose extremities appear to have been pressed together by the continuance of the pressure after the folds had been formed. (See Fig. 93.)

We generalize, therefore, the important principle of *lateral pressure exerted in the earth's crust.*

Given an enormous lateral pressure, then either the contig-

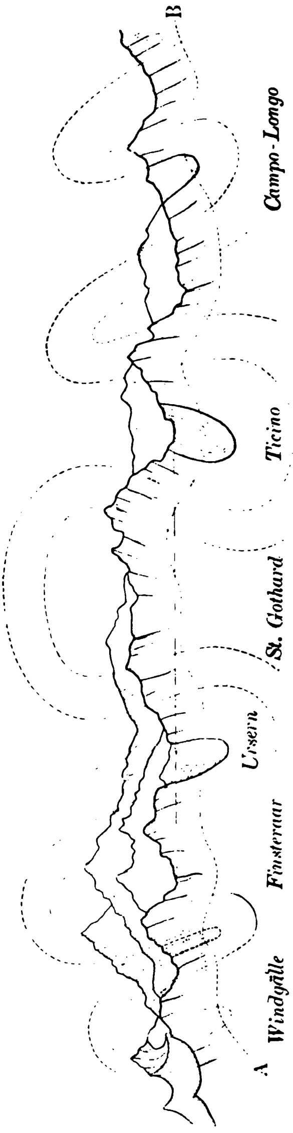


FIG. 93.—SECTION THROUGH THE ALPS, SHOWING THE EFFECTS OF LATERAL PRESSURE. (Heim.) The line of the St. Gothard Tunnel and the plane of equal temperature, *A B*, beneath it, are compiled from the Reports of the Italian Geological Survey.

uous parts of the crust will be crushed together and intermingled, or the crust will break and certain strata will slide over and between others; or, finally, the crust will suffer wrinkling, as shown in Fig. 94. When once a form like this has been inaugurated, then, evidently, all increased pressure from the directions *A* and *B* will tend further to elevate *a* and depress *b* and *c*. When, at length, the weight of the fold *a* becomes very great, pressure from the directions *A* and *B*, instead of lifting the fold higher, will develop new folds at *H* and *G*. The new folds will not arise until the weight of *a* becomes sufficient to overcome the rigidity of the crust at *H* and *G*. That is, when the crust is more rigid, the fold *a* will be sustained at a higher altitude. So we deduce the principle that *the highest mountains will come into existence in the epoch when the crust possesses most rigidity;* that is, in times geologically recent; because, through terrestrial cooling and continued sedimentation, the crust is becoming thicker and more rigid. A study of mountains confirms the deduction, since all the highest mountains are composed chiefly of Cænozoic and Mesozoic strata.

To illustrate further the effects of lateral pressure, and to demonstrate experimentally a probable origin of many mountains, M. Favre, of Geneva, devised the experiment set forth in Fig. 95. He spread a layer of clay on a stretched sheet of India rubber, and allowed the sheet slowly to contract. The sheet may be five-eighths of an inch thick, six and three-fourths inches wide, and sixteen inches long. When stretched to twenty-four inches, it may be covered with a layer of potters' clay from one to three inches thick, made as adherent as possible to the India rubber, with a block of wood applied at each end. The slow contraction of the India rubber develops the appearances seen in the figure. Now, when you carefully inspect this figure, you note several important points of resemblance to the mountain corrugations on the earth's surface: (1) There is a set of folds or anticlinals. (2) Some of the anticlinals are fractured along the crest. (3) The folds present a tendency to be elongated in a direction at right angles to the direction of the pressure. We note, also, other points: (1) The upper layers are more folded than the lower; the lower, therefore, must have been shortened by *squeezing together*. Perhaps the lower strata in the earth's crust have been similarly squeezed together, or, instead, have suffered an infinite number of small plications in place of large folds. (2) The corrugations are scattered over the entire surface, instead of being grouped like

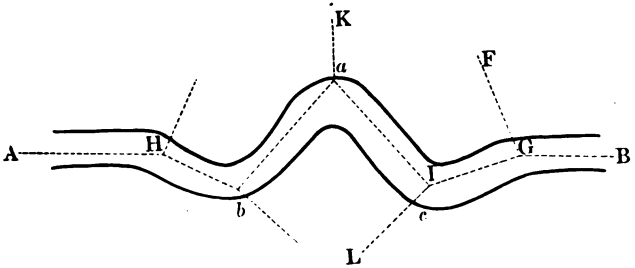


FIG. 94.—FORMATION OF WRINKLES IN THE EARTH'S CRUST, WITH PARALLEL CONTIGUOUS FURROWS.

mountain ranges, in a great chain. (3) The longitudinality and parallelism of the folds arise from the fact that the pressure was exerted from two directions. As mountains present similar characters, we may infer that they also receive pressure from two opposite directions. These seem to be facts and valid inferences as far as they go.

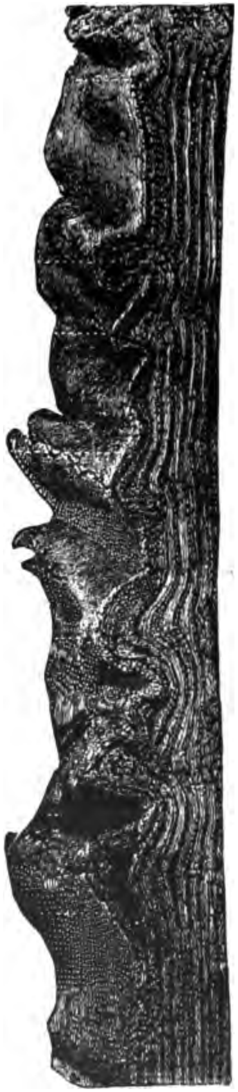


FIG. 95—ILLUSTRATING THE FORMATION OF MOUNTAIN WRINKLES. (Favre.)

In the results of mountain making we seem therefore to detect the evidences of enormous lateral pressure exerted from all directions, but especially from directions at right angles with the axes of mountain ranges. What data have we for inferring the origin of these pressures?

Now, our attention has been directed to some facts which seem to indicate that the earth is a cooling body, and has for many ages been cooling. A cooling process is a shrinking process. Hence the earth has contracted in volume; its circumference has become less. Now, if the matter of the crust or exterior had cooled at the same rate as the interior, the shrunken crust would still fit the shrunken interior, and so no wrinkling would be possible. But the crust is in a position between the heated interior and cold external space, and these contending influences hold the temperature of the crust at a point somewhat uniform; while all the heat emitted by the interior, in this contest, tends continually to reduce its temperature. While therefore, the interior shrinks, the crust retains its ancient circumference. It is therefore obliged to wrinkle to dispose of the surplusage.

But a general shrinkage of the earth would thus result in a process of crustal wrinkling having no relations to parallels or meridians. It would be a wrinkling like that of the skin of a withered apple. There must be, to produce our meridionally disposed mountains, some force acting more energetically from east to west than from north to south; or else there must exist in the crust some ingrained predisposition to yield to the action of east and west forces.

Now, I think it may be shown that both causes have existed, but the exposition of them would carry the elementary student too far. Let us therefore simply state the principles and await the opportunity for their full comprehension. (1) *The earth has shrunken more along its east and west circumference than along its north and south circumference.* This has resulted from diminishing oblateness due to gradually retarded rotation. (2) *Ingrained meridional predispositions exist.* I have elsewhere suggested that the tidal action of the moon while the earth was yet in the incrustive stage, must have implanted a meridional structure which predisposed to wrinkling more considerably in the north-south direction than in the east-west direction. Ocean pressures could have had no agency in *initiating* the direction of mountain trends, since the axes of the earth's folds existed before the oceans, and the bounds of the oceans were indeed determined by them from the beginning.

If we glance again at the plateaus of the Grand Cañon (Fig. 87), we see a vast region shivered by faults. We see great slabs of the earth's crust uplifted on one or more sides, sometimes to mountain altitudes. Now while some fracturing of the crust must have accompanied the actions which upraised mountain folds, we cannot conceive of huge unbent slabs as a product of action whose characteristic it is to produce bent and crumpled rocky sheets. Here we have the evidences of a force acting vertically, not tangentially. It is as if an ice-covered lake had been partially drained. The ice subsides and undergoes fracture along countless sub-parallel and intersecting lines. Should the lake be again filled, and then again drained, and this process several times repeated, the joints in the ice would be opened; there would arise dislocations. Some cuboidal masses would be lifted up. The accompanying lateral motion would throw some into confusion, and the whole would present some resemblance to the actual aspect of these plateaus. Now we have the evidence of a most copious escape of molten matter from beneath the crust of the plateaus during the later stages of the continent's history. In the present state of our knoweldge, perhaps we can do no better than to connect with these lava outflows such fluctuations in the level of the crust as might explain the great system of faultings so characteristic of western geology.

Thus, our attention has been directed to the most obvious characteristics of mountain forms and mountain mechanism; and we have tried to infer from the phenomena, the way in which the known forces must or may have acted to produce them. The methods of mountain making are not yet fully understood; but as far as we have here gone, our inferences probably represent the truth. The whole subject is too large and too difficult for the elementary student, and he should return to it in an advanced course.

EXERCISES.

Look at Fig. 92 and point out the easterly end of the section. Draw a line on the map showing where this section is located. What mountains does it cross? Why is it not drawn exactly east and west? What is the highest peak? What is its height? What is the lowest point and its elevation? If you were on the summit of the highest mountain, what would be the age of the rocks under your feet? Look at the Table of Types of Mountain Structures and point out the type to which this belongs. Point out others of the same type. How much do you estimate the highest mountain to have been lowered? By what means was it lowered? What type is Furnace Mountain? What type is the Hog Back? What is the length of this section as drawn? Notice the formation marked 7; what is the name of it? Suppose it restored from end to end of the section, then measure the total length with scale and dividers: how much is it? What percentage then, did this section shrink by being folded as it is? Point out here an anticlinal valley. Point out a synclinal mountain. What are the evidences that this section presents a series of folds? Why are the folds not perfect? Why was not the crust mashed into heaps instead of folded, by the great lateral pressure? Did any of the folds turn down? How many folds might be produced parallel with each other? Why would the central fold be highest? Why might not the sixth fold be highest? Would the folds be narrow in proportion as they are low? Should the rocks mash together what changes of temperature would be produced? Would the sliding of one stratum over another produce any thermal effects? Would the bending of the strata produce any? How high a temperature do you think might be produced by these mechanical actions? Might the heat be sufficient to melt the rocks? Suppose there were mere pressure, without motion, would heat be evolved? How might metamorphism result from mountain making?

STUDY XXVII. — *Veins and Ores.*

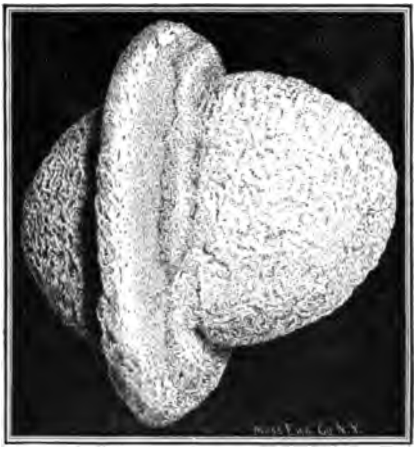


FIG. 96. — A QUARTZOSE VEIN IN A GRANITIC ROCK. (From a specimen in the University of Michigan.)

Let us return to the bowlder-strewn fields. We now fix our attention, not on the *kinds* of rocks, but on their structure. Everyone has noticed thin sheets of certain sorts of rock material cutting through a rock of some other sort. In bowlders these intersecting sheets sometimes become very conspicuous in consequence of the unequal weathering of the two kinds of rock. A sheet of this sort is a *vein*. Here is a notable specimen in the museum of the University of Michigan. The projecting part is a portion of a quartzose vein intersecting a mass of granite. This was once a fragment of granite containing a quartzose vein which was probably even with the general surface of the granite. Notice now how the vein projects. That seems to be only because the granite, hard as it is, has weathered away so much more than the vein. Many persons suppose the granite passes through the quartzose slab, like a plug. This excessive disappearance of the granite must be the effect of *weathering;* for any process of wearing which would remove the granite on all sides would also remove the quartz. Here, then, is a confirmation of the doctrine of rock weathering, to which we were brought by the facts considered in Study XVI.

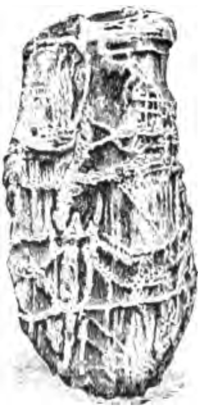


FIG. 97.
INTERSECTING VEINS SEEN IN A BOWLDER, ANN ARBOR.

In our wanderings among the bowlders, we often find a rock intersected by many veins. They present various forms. Sometimes they are smooth-sided and sharply distinct from the rock which they cut, as in Fig. 96. Sometimes they blend with the rock. Often they branch and pursue zigzag courses, and, splitting, unite again, inclosing portions of the rock. Here, in Fig. 97, is an interesting example, full of instruction, but not at all infrequent. Study the forms and ramifications of these veins. In some cases the different veins appear to be but branches of one vein; but what must we say of a rock like this shown in Fig. 98, where the veins are of different sorts of material, and intersect each other in a complex fashion. This shows a surface of syenite on the beach at Salem, Mass. It is thirty-six feet by twenty-seven feet. It was brought to notice by Dr. Edward Hitchcock many years ago. Contemplate it attentively. These numerous intersecting sheets are all veins. But as there are numerous intersections, it is obvious that an intersecting vein is more recent than one intersected. So the one which intersects all the others is the last. The oldest is the one intersected by all the others, or by others which are themselves intersected by all the remaining ones, or by those which are finally so intersected. These veins are numbered, and you may exercise yourselves in showing that they are numbered in the correct order. Veins 2, 5, and 9 are diabase; veins 3, 4, 10, and 11 are of reddish granite; vein 6, which is forty inches wide, is a porphyry, and vein 7 is also a porphyry; vein 8 is granitic. Here are ten different epochs of vein formation. The syenite mass has been rent at least ten different times, and after each movement some sort of vein material has filled the fissure. Was the material injected from below in a molten state? Or did it infiltrate in solution from the contiguous rock? Or was it poured in from the top, either in a state of fusion or solution? These questions present themselves for reply; but the answers are not obvious, and we had better postpone their consideration till we get other facts.

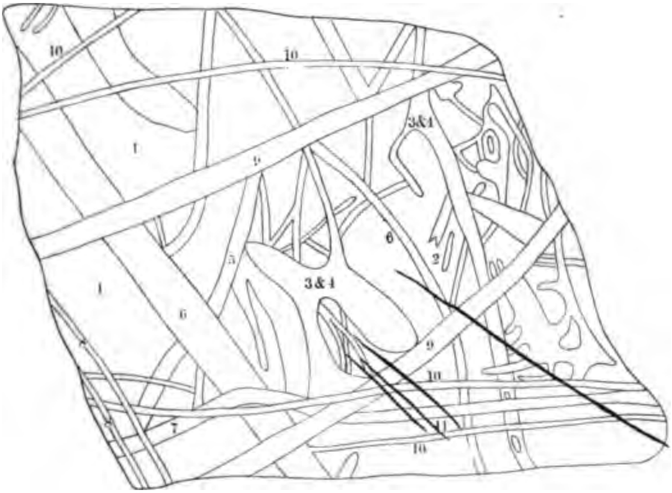


FIG. 98.—VEINS IN SYENITE ON THE BEACH AT SALEM, MASS. (E. Hitchcock.)

A little attention will bring to our notice veins having various contents. Besides the materials mentioned, we often find orthoclase, in large crystalline masses, filling veins; sometimes calcite, beautifully crystallized; sometimes pyrites, or galena, or blende. All these cases, and others, occur among bowlders. In metalliferous regions it generally happens that several different minerals occur in one vein or *gangue*. They are, then, sometimes arranged in alternating layers parallel with the rock wall, and each layer is called a *comb*. In a regular combed vein the combs are symmetrically arranged on each side of the centre. This is shown in the annexed Fig. 99, where *A A* represent the *country rock*, or rock formation, holding the vein, and the bands *a*, *b*, *c*, etc., are seen in a section across the filling of the vein fissure, from wall to wall. Here it appears, that after the fissure was opened, the layers, or combs *a*, *a*, were first laid on the fissure walls. Then, under changed conditions, the layers *b*, *b* were laid upon the first. Subsequently, with further changes, the layers *c*, *c* and *d*, *d* were deposited. Sometimes, as in the "Three Princes Vein," near Freiberg, the number of combs is much greater. This vein, Fig. 100, presents six different species of minerals, occurring in eleven different combs on each side of the middle — four of the sorts being repeated. Examination of this diagram will show the method of arrangement, and also the minerals of most frequent occurrence in metalliferous veins or ***lodes***.

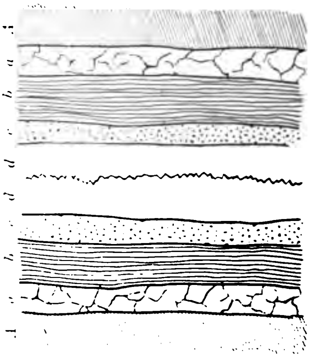


FIG. 99 — SECTION ACROSS A VEIN FISSURE AND ITS CONTENTS, SHOWING A COMBED VEIN OF SIMPLE SYMMETRY. (Von Cotta.)

Minerals do not associate themselves together in lodes in a promiscuous manner. When two minerals are present, they are likely to be galena and blende, iron pyrites and chalco-pyrite, gold and quartz, cobalt and nickel ores, magnetite and chlorite, and so on. If three minerals are present, certain rules are also observed; and if more than three, the geologist has learned what to expect together. This association of minerals is known as *paragenesis*.

To illustrate further, in this connection, some of the principal sorts of veins, the diagram, Fig. 101, is annexed. A *true vein*, *a*, is one which traverses a formation independently of its texture and position. A *bedded vein*, *b*, traverses the *country* parallel to its stratification or foliation; but a sedimentary layer must not be mistaken for such. A bed of coal is not a vein. A bedded vein often sends out branches. A *contact vein*, *c*, occurs between two dissimilar formations. A *lenticular* vein, *d*, *d*, thins out in all directions. It must be distinguished from lenticular beds. It bears no relation to the stratification, and is, in fact, only a true vein pinched in two in several places.

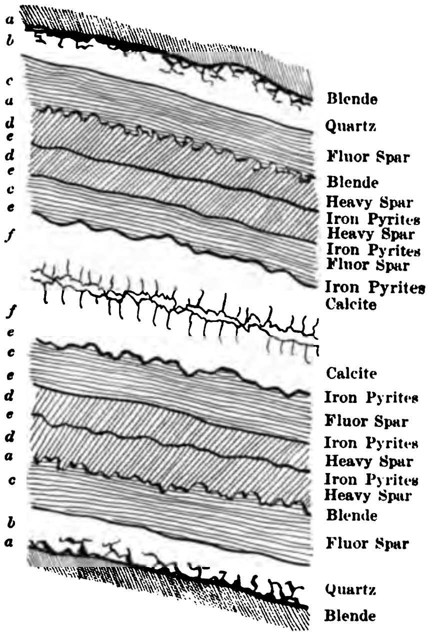


Fig. 100.—The "Three Princes Vein," near Freiberg. (Von Weissenbach.)

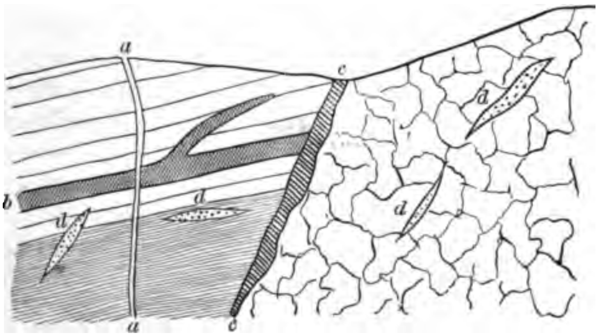


Fig. 101.—Different Sorts of Veins. (Von Cotta.)

Most metalliferous ores occur in veins; but there are very important exceptions. Many rich lead mines occur in crevices or caverns in limestones, which are lined by the ores of lead and zinc. (Fig. 102.) *Placer mining* is a process of washing gravel and sand to separate the intermingled metallic particles. (See Study XXIV.) The great beds of magnetite and hæmatite occur mostly in huge lenticular masses conformable with the stratification of the inclosing schists. The masses shown in Figs. 103 and 104 are portions of such lens-shaped beds in northern New York. In Figs. 105 and 106 entire masses are shown. Here it is apparent that the ore belongs to the same system of stratification as the country rock; and in fact, the lines of bedding often pass uninterruptedly from the rock through the ore. (See especially Fig. 105.) This indicates that the ore is *segregated*, or separated subsequently to the deposition of the original sediments—a conclusion similar to that before reached in reference to certain concentric structures. (See p. 48.) That the great beds

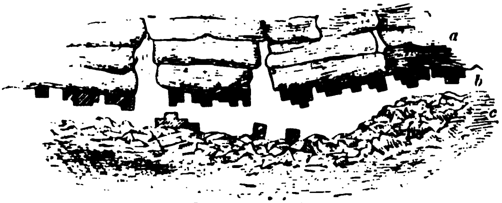
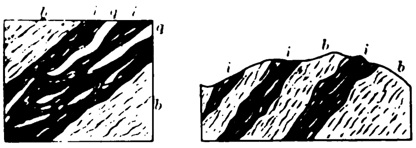
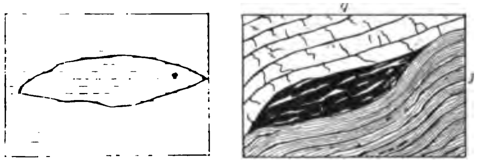


FIG. 102.—CREVICE IN LIMESTONE, SHOWING OCCURRENCE OF GALENA AT SHULLSBURG, WIS. (Whitney.)
a, Cap Rock. *b*, Opening, with galena. *c*, Rock and detritus.



FIGS. 103 AND 104.—OCCURRENCE OF IRON ORE IN ESSEX COUNTY, N. Y. (E. Emmons.) *i*, Beds of ore; *q*, Included masses of quartz or other rock; *b*, Country rock.



FIGS. 105 AND 106.—LENTICULAR MASSES OF IRON ORE INTERSECTED BY LINES OF BEDDING. (After Brooks.)
105. Slaty, and blending with "country rock." Vulcan Mine, near Waucedah, Wis.
106. Hard, with hanging wall of quartz, *q*, and "foot wall" of jasper, *j*. Marquette Range, Mich.

of hæmatite and magnetite were originally involved in the sedimentary process is still more clearly shown in cases where the rocks are less metamorphic and the ore (generally a "lean" ore) presents continuous beds as shown in Fig. 107, *H*, where the iron schists are conformably interstratified in a section from the eastern portion of the Penokie range.

Metalliferous deposits are not to be sought for indiscriminately. In general, metamorphic rocks are more productive than others. Certain products, also, are more likely to occur in rocks of certain age. Finally, certain principles of association of minerals (paragenesis), as before stated, serve as a clew to the discovery of particular metals. A few examples will illustrate the distribution of the metals.

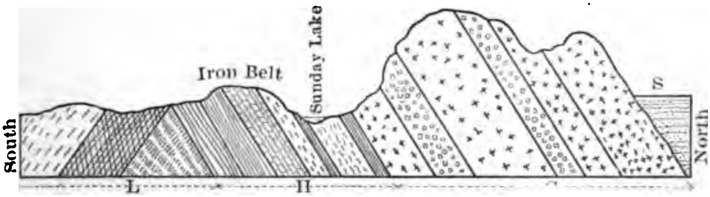


FIG. 107.—SECTION THROUGH AN IRON RANGE IN WESTERN MICHIGAN BETWEEN LAKE GOGEBIC AND MONTREAL RIVER, SHOWING POSITION OF THE IRON ORE, AND THE RELATIONS OF FOUR SYSTEMS OF ROCKS. (Pumpelly and Brooks.) *L*, Laurentian Granites, Gneisses, and Schists: *H*, Huronian Slates, Iron Schists, Quartzites, and Diorites; *C*, Copper-bearing Rocks (Keweenian), "South Range"; *S*, Sandstones of Cambrian Age.

Iron is quite universally distributed. The great beds of magnetite, hæmatite, franklinite, and titaniferous iron are located in the metamorphic strata of Eozoic age. In America, the two former occur chiefly in northern New York, northern Michigan and Wisconsin, and southern Missouri. In Sweden nearly all the celebrated iron mines are of magnetite from Eozoic rocks. Titaniferous iron ore occurs at many localities in the United States, Canada, Norway, and other countries. Franklinite is mined at Hamburg, N. J. Siderite ranges from the Eozoic to the Carboniferous strata, and in smaller quantities to later strata. In the coal measures of Pennsylvania, Ohio, and elsewhere, it occurs as an argillaceous ore, in nodules, and beds of clay-iron-stone.

Limonite occurs in Mesozoic and more recent deposits; and also, as bog iron ore, in modern marshes; also, by hydration of hæmatite, in rocks of greater age, as in Salisbury, Conn., and thence through Pennsylvania and Tennessee to Alabama.

Lead, as galenite, and sometimes lead carbonate or cerussite, occurs in pockets and fissures of the Lower Cambrian limestone in Missouri and of Upper Cambrian ("Galena") limestone in Iowa, Illinois, and Wisconsin. Its mode of occurrence is shown in Fig. 102, the cubical crystals of galenite attaching themselves to the limestone surfaces, and sometimes attaining a weight of sixty to seventy pounds. Galenite also occurs in veins, in gneiss, granite, argillite, and crystalline limestone, in various parts of Europe, New York, and New England, and in the Carboniferous Limestone of England and the continent. Galena is often worked, as at Leadville and in the Eureka district, for the silver contained in it.

Copper occurs in veins in metamorphic rocks of Europe and America. Its principal ores are copper pyrites or chalcopyrite, chrysocolla, malachite, and azurite. Native copper occurs in beds and veins in the vicinity of dikes and beds of igneous origin. In northern Michigan the associated rocks are now thought to be of Keweenian age—that is, next older than Cambrian. In New Brunswick, New Jersey, Connecticut, and California, they are Mesozoic. At some localities on Keweenaw Point and in Europe in the "Thuringian copper slates," small particles are collected in large abundance, as a sort of drift copper, deposited in beds. Copper ores are partial to chloritic and hornblendic schists, dolorites, and serpentines.

Silver is found native with the native copper of Lake Superior, and also elsewhere in veins traversing gneiss, schists, porphyry, and other rocks. In the form of ores, the most valuable are argentite or "silver glance," stephanite (both abundant in the Comstock lode, Nevada), cerargyrite or "horn silver" (chloride) in veins of clay slate in Nevada, Idaho, Arizona, and South America. Argentite is very commonly found with galenite.

Silver ores prefer silicious or argillaceous rocks to limestones or dolomites. They also appear to avoid granite and red gneiss.

Gold is found only native, but it is very frequently alloyed with silver, palladium, or rhodium. Its native place is quartz veins intersecting metamorphic rocks, mostly chloritic, talcose, and argillaceous schists. These range in age from the Eozoic to the Tertiary. Gold avoids lime. The breaking up of the schists has caused native gold to appear in the drifts of many regions; and from these most of the world's supply has been obtained. (Study XXIV.) The exhaustion of the "placers," however, has driven miners very extensively to the quartz lodes in the mother rock. The celebrated Comstock lode, which yields gold and silver in nearly equal proportions, is mostly a sheet of crushed quartz, dipping eastward 33° to 45°, with a length of four or five miles and a maximum thickness of about six hundred feet. It has been mined to a depth of three thousand feet, where the enormous outflow of water is found to have a temperature of 170°.

Tin is found, as cassiterite, in rocks of great age — mostly eruptive and metamorphic — never in limestones or dolomites. The world's supply has come chiefly from Europe; but mines are now worked near Harney, Dak., and deposits which promise to grow valuable are reported from Mexico, Idaho, Montana, Wyoming, and New Mexico, as well as from Custer and other localities in Dakota.

EXERCISES.

Correct this expression: Mr. A. has a vein of coal on his farm. If Mr. A. has a bed of coal, has he probably native silver also? What metalliferous ores might he have? What are the prospects of a man exploring for coal in dark metamorphic slates? What common mineral is most frequently mistaken for gold? Suppose pyrite and gold are both heated on a shovel, what variations in color do they undergo? What is pyrite composed of? What is the source of the acrid fume when pyrite is heated? Is it probable any gold could be found in your neighbor's garden? Whence comes most of the copper of the United States? In what form is it found? Explain how native copper may occur in the drift of Ohio or Illinois. Did you ever hear of its occurrence in those states? Would it be possible for native silver to occur at Columbus, Ohio? What is the age of the rocks at Columbus? Would native silver, if occurring there, be found in the solid rocks or in the drift? Look at Fig. 98, and state whether vein No. 3 was the first formed vein there shown. How do you reason on the subject? Have you noticed that granite has been treated as a sedimentary rock, and that here it appears as a vein? Can a vein be also sedimentary? Could this granite vein be dissolved by any means? What substances may we conceive in the water which saturated this syenite at a former time? Can you think how the granite vein could have been deposited through its walls? Do you regard it probable that any veins have been filled by injections of melted matter?

STUDY XXVIII.—*Geology of Salt.*

Key West is an island about four miles long and nearly one broad. Through the centre, for two and a half miles, extends a series of ponds, which are one or two feet lower than medium high tides. The ponds seem to have been formerly connected with the sea, and to have been cut off by the ridges of sand thrown on the beach by the waves. The separating ridges, though higher than the ordinary tides, are still lower than the high tides, which occur twice a year — in early winter and in midsummer. The high tides, therefore, flow into the ponds. After the ponds have thus been filled, or partially filled, by the winter tides, they remain exposed to the powerful evaporative influence of the sun until the next midsummer. By this time the water is much condensed. Another influx of high tides restores, perhaps, the volume of water, but the resulting brine is salter, since no salt went out by evaporation, though additional salt now comes in. During another period of mean tides a large amount of evaporation again takes place, and the contents of the ponds become denser than before. This process has gone forward before our eyes. We know it is a fact. By and by it has been repeated so many times that the brine is completely saturated. Then, when the next high tides flow in, and the next evaporation follows, the oversaturated brine begins to deposit its excess of salt. The next year more salt is deposited. Thus, in course of time, the ponds contain a supply of saturated brine, and the bottom is covered by a bed of salt. Now, this condition was actually reached when the state of things was discovered by the crews of vessels which made a landing, and raked large quantities of salt from the ponds and carried it away. These things are matters of observation. Let us think about them.

Suppose some large bay or gulf should become cut off from the ocean, so as to have communication with it only at high tides. Suppose, for instance, it should be the Red Sea. Then, if the evaporation during the year were greater than the supply of fresh water from the inflowing streams and the clouds, each year's evaporation would increase the density of the water. If, occasionally, through high tides, or extraordinary storms, there should be a fresh influx of sea water, the amount of salt eventually introduced into the basin would become indefinitely great, and, crystallization of salt having at length begun, the amount deposited would increase until the conditions should change. Some sediment, more or less, would find its way, also, into the sea, and would mingle with the precipitated salt. The sea would thus be gradually filled up. It is supposable that the obstruction at the straits might finally increase until all access of the Indian Ocean should be prevented. This might result from an elevation of the region about the straits. The filling of the basin would now be completed, chiefly by fragmental deposits. Or if, before the filling of the basin, a subsidence should be experienced, a new influx of the ocean would bring new beds of sediments over the salt accumulations precipitated and buried in a previous age. If, instead of subsidence, or if, after a period of subsidence and sedimentation, there should be an elevation of the region, then it would become a part of the land. We have already learned that events of this nature have taken place again and again in the history of the world.

Suppose we stand upon that land. There are beds of salt under us. If we dig down, we shall sooner or later reach them. These salt beds were once the bottom of the sea. We may find more or less pure salt; but we shall certainly find, also, the mechanical sediments which were borne into the sea while the salt was crystallizing, and after the salt had ceased to crystallize. We shall find, also, everything which was originally in the sea water.

What, now, shall we conclude when we see men digging salt from the earth in the county of Chester, near Liverpool? Here, at Northwich and Winsford, after penetrating through gypsoous clay 120 feet, beds of rock salt are found sixty to ninety feet thick. Beneath these are indurated clays for thirty or forty feet, containing beds of rock salt, and below these, 100 feet more of rock salt. Much of this salt is earthy, but some is quite pure. The salt is dissolved, often in sea water, and then evaporated in pans by artificial heat. This is what we see going on at the surface. Are we not led to conclude that here, in Cheshire, is a salt formation quite similar to the one which we supposed formed in the Red Sea? When we look about, we see Cheshire lying in a geological trough, bounded by the hills of Yorkshire on the northeast, and the highlands of Wales on the southwest. The formation filling the trough is the Triassic. We can understand that that valley was once a bay projecting inward from the Atlantic Ocean, and was probably filled precisely as we have supposed of the Red Sea.

We may subject this conclusion to severer tests. If we take a portion of sea water and evaporate it, we find precipitated successively peroxide of iron (not in all cases), gypsum, common salt, and epsom salts, or magnesium sulphate. Calcium, magnesium, and potassium chlorides remain. If we take the natural brine from a well in Cheshire or Syracuse, and evaporate it, the same succession of precipitates is obtained. The peroxide of iron is thrown down in the "clearing vats." The gypsum forms the first crust on the bottoms of the kettles or pans. The common salt is next crystallized out (in part), and the chlorides remaining form the "bitterns." Examining more closely one of the salt formations — for instance, the Salina — we find in the lower beds some ferruginous clays; above these, gypseous clays, and clays with masses of gypsum arranged in horizontal courses; still higher, supplies of brine, and in many districts, vast beds of rock salt. Still above are limestones with acicular cavities, which seem to have been once occupied by needles of epsom salts. Here is a close correspondence, and on these evidences we may rest our theory of the origin of salt formations.

The theory is not intended to apply to cases where salt is confined to a vein or dike, as at Bex, in Switzerland. Sometimes, undoubtedly, streams have been fed by brine springs issuing from older formations, and, discharging into inland lakes without outlets, have undergone evaporation and produced new salt formations. Some of the salt lakes of our western territories probably have an origin of this sort; but their remote origin was in the sea water which salted the salt formations which now surround or underlie them. The Caspian and Aral seas, however, are undoubtedly remnants of the ancient ocean; and when they disappear, salt formations will occupy their sites. The process is already far advanced in many of the bays of the Caspian and the outlying lakes along its borders.

Turn once more to the geological map, page 118, and fix attention on the formations stretching east and west through central New York. They all dip southward, or away from the Eozoic of Canada. We once constructed a section from Canada to Pennsylvania (Fig. 53), which shows this dip, but greatly exaggerated. Now, the Salina group, which is the great salt formation of New York, occupies a position in the upper part of the Silurian, as you must remember (see Fig. 39). The Helderberg, which holds a place above it, is almost wanting in central New York, and consequently the outcrop of the Salina at Syracuse is close by the lowest Devonian — that is, the Oriskany sandstone and the Corniferous. Its place may be marked on the section Fig. 53.

Now let us make a section on a larger scale for the purpose of showing more clearly the geological position of the brines obtained at Syracuse and worked under the auspices of the state for about a hundred years (Fig. 108). Here we see the Salina formation excavated at its outcrop. The excavation has become filled with drift materials. A depression remained in the drift which permitted a shallow lake to exist for a geologic period;

but this has now shrunken to the present Onondaga Lake which is bordered on the south by a marsh. Beyond the marsh is the hard ground on which Syracuse is built; and beyond this rises a hill underlaid by the Corniferous and Onondaga limestones. On the slope of the hill may be found some outlying fragments of the Oriskany sandstone. Now, the brine which saturates some portions of the Salina strata, overflows at the border of the formation, and saturates the bed of drift material filling the excavation just mentioned. The rains falling on the surface rest on the top of the denser brine, instead of settling down, and the surplus flows into Onondaga Creek. Accordingly, the wells dug in the saturated drift receive a supply of brine; and the deepest ones obtain the strongest brine. These are about 400 feet deep.

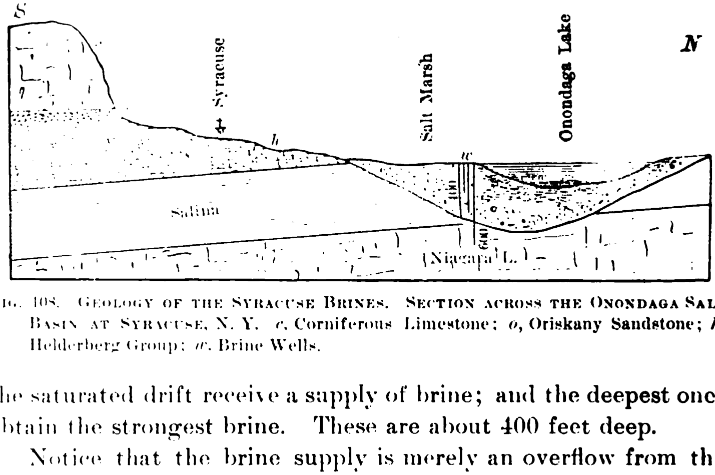


FIG. 108. GEOLOGY OF THE SYRACUSE BRINES. SECTION ACROSS THE ONONDAGA SALT BASIN AT SYRACUSE, N. Y. *c*, Corniferous Limestone; *o*, Oriskany Sandstone; ***h***, Helderberg Group; *w*, Brine Wells.

Notice that the brine supply is merely an overflow from the formation, and must be comparatively weak and limited in amount. But notice that the formation to the south of Syracuse sinks to a greater depth. From this it may be inferred that artesian borings some miles south would reach stronger supplies, and perhaps even a bed of rock salt. Farther west, in Wyoming county, experiments of this kind have disclosed the existence of large supplies of native salt.

Referring to the map again, it will be seen that the Silurian passes in a basin slope under the peninsula of Michigan and lakes

Huron and Michigan. The Salina which lies near the top of this, outcrops on the east, at Grand River in Ontario; on the west, at Milwaukee; on the north, at Mackinac and on the south, at Sandusky. This basin retains, therefore, all its ancient salinity. Accordingly salt borings carried to the appropriate depths in almost any part of the peninsula, reach either abundant strong brine or a thick bed of salt. The diagram Fig. 109, illustrating these relations, shows a gradual increase in the depth of the salina basin, as we approach the centre of the peninsula. The salina formation is productive on the eastern and western borders, and on the northeast in the Huron peninsula, and at Alpena on Thunder Bay.

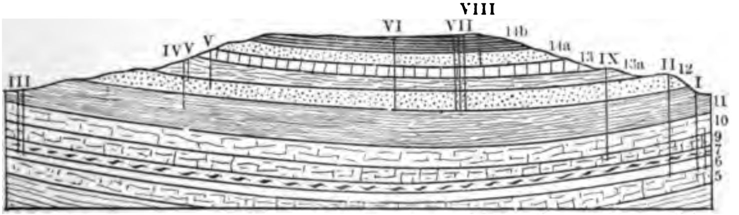


FIG. 109.—GEOLOGY OF MICHIGAN BRINES. (Vertical Scale much exaggerated.) Formations indicated by numerals (see Table, Pt. II. ch. ii). 11, Huron Group, consisting of Genesee Shale, Portage and Chemung; 12, Marshall Sandstone; 13*a*, Michigan Salt Group; 14*a*, Parma Sandstone (Coal Conglomerate). Geological Positions of Brine Wells: *I*, St. Clair Group; *II*. Port Austin Group; *III*. Manistee and Muskegon; *IV*, Original Well, Plaster Quarries; *V*, Grand Rapids; *VI*. Lansing (last three unproductive); *VII*, Saginaw Valley; *VIII*, Bay City, shallow wells; *IX*, Ann Arbor Artesian Boring, 755 feet (no result).

But the characteristic salt formation of this state is the "Michigan Salt Group", which constitutes the lower part of the Carboniferous Limestone (see Fig. 39), and whose position is shown in the preceding diagram. This basin underlies the greater part of the peninsula. As the strata are too compact to permit the extensive accumulation of brine, the brine sinks into the underlying sandstone, known as the "Marshall Sandstone," and indicated in the "Geological Column" as the probable equivalent of the "Catskill Group" at the bottom of the Carboniferous System — or as many think, at the top of the Devonian. The densest brine, as in other cases, is somewhat remote from the outcropping border of the Marshall reservoir, though the line of outcrop is marked by a circle of salt springs. This basin supplies the celebrated wells along the valley of the Saginaw River. No native salt is known to exist in the Michigan Salt Group, and it is apparent that the brine will eventually become exhausted. The group contains enormous deposits of beautiful gypsum. This exists in a continuous stratum from side to side of the peninsula. It shows again the same association with salt as occurs in sea water.

Still another salt basin is formed in Michigan by the Coal Measures. The brine accumulates in the underlying "Parma Conglomerate." (See Figs. 39 and 109.) The shallow wells at Bay City, on the Saginaw River, are supplied from this source. The generally saliferous condition of the formations in Michigan seems to depend on their dish-like conformation. As a result of this, they have retained most of the soluble constituents left in them by the ancient sea water. There are even indications that a productive salt basin exists between the Salina and the Marshall sandstone, in the so-called "Huron Group," which embraces the "Chemung" of Fig. 39. These strata are everywhere saturated with brine and "bitterns"; and they supply the numerous "mineral wells" of the state.

Strata belonging to the horizon of the Michigan salt group are similarly productive of brine and gypsum in Nova Scotia and New Brunswick. The brine accumulations in Ohio seem to be in the Waverly sandstone; those of Kentucky are in the "knobstones," and those of Tennessee are in the "silicious group." These are all the geological equivalents of the Marshall sandstone.

Other salt deposits of the western United States are found in the Cretaceous. The salt and gypsum deposits at and near Saltville, in Washington county, Va., are thought by Stevenson to be not older than Tertiary. The salt is from 200 to 500 feet thick, mingled with some red clay; and the gypsum occurs in detached masses, enwrapped in the clay. The basins are excavated along a fault which has brought Lower Carboniferous and

Cambrian formations into juxtaposition. The singular formations at Petite Anse, La., are probably also Tertiary or Post-Tertiary. Most of the salt formations of Europe are in different members of the Triassic. Those of Russia are in the Permian; those of the Austrian Alps, in the Jurassic; those of the Pyrenees and of Cardona, in the Cretaceous; while those of Wielicza, in Galicia, of Tuscany and Sicily, are Tertiary. Salt also occurs as a volcanic product. The borings at Stassfurt, Germany, have penetrated 1,066 feet of Triassic rock salt, and at Sperenberg, 5,084 feet, without reaching the bottom. The Stassfurt salt manufacture is important.

EXERCISES.

If the Mediterranean is salter than the open sea, how can the fact be explained? If the Black Sea were not salter than the Atlantic, how might the fact be explained? Why is it necessary to redissolve the salt found native in Cheshire, England? What caused the clayey state of some of the salt? Was the salt deposited as a sediment? How might gypseous deposits occur above salt beds as well as below? What is the cause of the rusty stain seen in some inferior samples of salt? What causes the moist condition of some inferior salt? Would pure salt be best obtained by slow evaporation, or by rapid? Will you explain why? What position of the strata is most favorable for retaining their brine? What position is favorable for getting the salt leached out? Draw a diagram showing how a salt formation might become destitute of brine. In boring a salt well, would veins of fresh water sometimes be passed? How could fresh water be prevented from running down and mixing with the brine? Suppose the Michigan salt basin full of brine; where would the surface level stand? Could the brine be anywhere higher than the border? Suppose the border deeply notched on one side, where would the surface level of the brine be? Is the surface of the land above or below the probable surface level of the brine in that basin? If higher. will the brine then rise to the level of the land? (See Fig. 109.) Why could not a brine well be a flowing well? May the water from a flowing well be brackish? Draw a diagram explaining your view. In a fresh-water artesian well must we also have a basin arrangement? Would a flowing well be possible with a basin arrangement? Suppose the rock arrangement for a flowing well such, for instance, as supplies Chicago (Fig. 55), should be filled with brine, would we not have a flowing well of salt water? Would it last indefinitely? What would it become, and why? Why must a flowing well be a well of fresh water? Then how can we have a permanent flowing mineral spring?

STUDY XXIX.—*Geology of Petroleum.*

At the mouth of Thunder Bay, of Lake Huron, is a little island known as Sulphur Island. It rises but a few feet above the level of the water, and its surface is strewn with a deep bed of water-worn fragments of black bituminous shale (see Study XI, and especially XIII). A few years ago some fishermen built a camp fire on the the bed of shale, and the shale itself took fire and burned deep into the ground, and continued to burn for some months. The pieces of shale were not reduced to ashes, but retained their form. The bituminous matter burned out and they were left with a reddened appearance. Indeed the bitumen was seen to fry out of the heated fragments and become ignited. Near by, on the main land, is a solid bed of this shale, and there are some fossils in it which we have found nowhere except in the "Genesee Shale" at the top of the Hamilton Group (Fig. 39). Now this Genesee Shale extends from Central New York into all our western states. The observation at Sulphur Island, and similar ones elsewhere, suggest that the formation contains an enormous supply of bituminous matter. Bituminous matter is not always exactly the same. It is everywhere composed of carbon, hydrogen and a little oxygen. Carbon and hydrogen combine in many different proportions to form hydrocarbons. Some of the compounds are solid or tarry, some are liquid and some are gaseous. Examples of these are asphaltum, coal tar, kerosene, naphtha, benzole, illuminating gas (Study XIII). The bituminous matter which heat expels from the Genesee Shale is a mixture of several of these. What we call kerosene, then, is contained in Genesee Shale.

Reasoning in this way, the enterprise was instituted some years ago, of extracting burning oil from black shales. It was successfully done at Dartmoor in England, Autun in France and Bühl in Prussia. It was much more successfully done in Breckenridge county, Kentucky, from cannel coal, which is only a black shale peculiarly rich in carbon and hydrogen. It can be done with greatest success from certain substances known as Torbanite, Albertite and Grahamite. But all undertakings of this class were rendered profitless, about 1859, by the discovery of enormous supplies of natural oil on Oil Creek, in Pennsylvania; and afterward in many other regions. This natural oil, or *petroleum*, is essentially a bitumen. It consists of several hydrocarbons mixed. In different localities, it is light, or amber-colored or dark; it is thin, or dense, or tarry, according to the proportions of the lighter and heavier compounds. It closely resembles the substance obtained from black shales by artificial distillation. Is it possible the native petroleum comes also from black shales through a process of natural distillation? Let us examine the circumstances. In western Pennsylannia, the oil is found accumulated in porous sandstones some hundreds of feet below the surface. They are in part, at least, sandstones of the Chemung Group. Below them lies the very same Genesee Shale before referred to (see Fig. III). Should that undergo a process of distillation, the products being lighter than water would rise through the water-saturated rocks to some formation in which it could not escape. Suppose the depth to be 800 feet; is it allowable to assume the temperature at that depth sufficient to promote a distillation, however slow? In our judgment it is allowable.

Let us examine the situation in other localities. At Oil Springs and other points in Ontario, oil has long been obtained by boring through surface clays into the Hamilton limestone — a depth of one, two, or three hundred feet. This is quite below the Genesee Shale. But there lies at the bottom another and very similar black shale, called the Marcellus. So the same kind of a source is present as in Pennsylvania. But instead of a porous sandstone here to serve as a reservoir, we have the shattered and cavernous limestone; and the clayey covering of drift shuts it in (Fig. 110. *II*).

But we find in Ontario another quality of oil, derived from another source. In the same township are wells which consist of shafts sunken through the drift to the rock, and these obtain a dark and tarry petroleum, which is used for lubricating purposes (see

Fig. 110). The diagram shows the Genesee Shale above the Hamilton Limestone extending under the region of these wells. This becomes the source of oil which rises into the gravel bed at the bottom of the drift and saturates it, and thence flows into the well. But the oil undergoes some evaporation in consequence of the partially pervious character of the drift, and hence appears more tarry than the oil from greater depths. Both situations here favor our conjecture. Let us turn to West Virginia.

Here we find ourselves over the Coal Measures; and find likewise, two situations in which petroleum accumulates. First, we get the principal accumulation in what probably answers to the Conglomerate (Fig. 111), and we find below, a series of Sub-Conglomerate Coal Measures, which are indicated in Fig. 39. These, like the true Coal Measures, contain strata of dark bituminous shale. The Sub-Conglomerate Shales are, therefore, in the precise position to answer the same purpose as the similar Genesee and Marcellus Shales in the other cases. Oil also accumulates in the Conglomerate in southwestern Pennsylvania, southeastern Ohio and northeastern Kentucky.

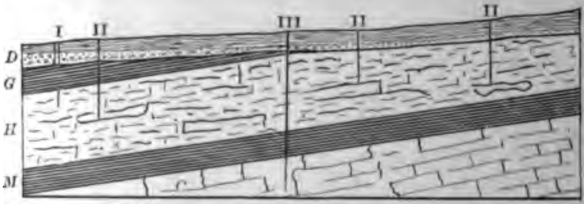


FIG. 110.—GEOLOGY OF PETROLEUM IN ONTARIO. *C*, Corniferous Limestone; *M*, Marcellus Shale; *H*, Hamilton Limestone; *G*, Genesee Shale; *D*, Drift, with gravel at bottom and impervious clay above. *I*, "Surface Well" at Oil Springs; *II*, Common bored wells; *III*, Test well, bored 600 feet.

Secondly, we find some oil accumulated in the sandstones of the proper Coal Measures. Some of the interstratified black shales lie beneath the horizon of oil accumulation, and are, therefore, in position to yield oil by distillation, which may rise into the sandstones.

On the Cumberland River, in southern Kentucky, many years ago, in boring for salt, a large supply of oil rushed forth. The situation here is on the Trenton Group of the Cambrian. (Fig. 39.) When we come to a detailed examination of this group, we find the upper half of it (Cincinnati sub-group) composed of shales, marls, and limestones. In New York the divisions of this sub-group are named Hudson River Slate above and Utica Shale below; and the latter is described as "a dark-colored slate frequently loaded with carbon" (Mather), and, indeed, often ignorantly explored for coal. Now, wherever this condition of the lower part of the Cincinnati sub-group exists, we have the same provision as before for the evolution of petroleum. On the Great Manitoulin Island of Lake Huron a small amount of oil has also been obtained from the Cincinnati sub-group.

In the neighborhood of Glasgow, Ky., some petroleum has been obtained. The locality is on the shattered and cavernous Carboniferous Limestone; and the fluid accumulates in the fissures, as in the fissures of the Hamilton Limestone of Ontario. Underneath we find some silicious, dark-colored shales, and below these the widespread Genesee Shale full of hydrocarbonaceous matter, as elsewhere. (Fig. 111.)

In this survey of the facts we find that oil accumulation sustains no uniform relation to deposits of coal. The oil is not derived from coal. The situation in every oil region, except West Virginia, is geologically below the coal, and geographically remote from coal. Nor do we find in beds of coal any exudation of oily matter, while in black shales we generally find it. In Carbonaceous Shales the hydrocarbons manifest a predisposition to form and escape. Mixture of aluminous matter with the carbon may be the predisposing cause. Beds of carbon nearly free from argillacous matter do not undergo the change.

We should not overlook the fact that many limestones—especially the Corniferous and the Niagara—are in some regions densely charged with bituminous matter. This fact has led to the opinion that the source of the oil is in limestones rather than black shales. Accordingly, a "test well" was bored at Oil Springs, Ont., six hundred feet deep, and the Corniferous Limestone was penetrated (Fig. 110), but without any additional supply of oil. The same limestone has been many times penetrated in Ohio and Michigan, but no supply was ever reached. The tarry Niagara Limestone was bored into in Chicago, but artesian water was obtained instead of a supply of oil. (Fig. 55.)

It seems reasonable now to infer, from the uniform relations of the facts, that some carbonaceous, shaly formation is always the source of the petroleum, and that it is eliminated from this by a slow process of spontaneous distillation, under the influence of such temperatures as exist within the crust of the earth.

The following, then, are the conditions of oil accumulation in quantities of commercial importance:

1. *A source below*, from which the oil is elaborated. This we find from observation to be always a bituminous shale.

2. *A reservoir above*, in which the oil is accumulated. This is a sandstone, or a shattered limestone, or shale.

3. A slightly *anticlinal position* of the reservoir, to prevent the lateral spread and wastage of the oil.

4. An *impervious covering*, to prevent the escape of the oil to the surface and volatilization there.

If the reservoir is wanting, the presence of the shale is unavailing. If the anticlinal is crowned by a break, it may result in the escape of the oil. In the course of ages the volatilization of the light hydrocarbons may leave a fissure filled with the solid residue. Thus is formed the Grahamite of West Virginia, and also the Albertite of Nova Scotia. If the impervious covering is wanting, the oil may rise to the surface, and a residue, like that forming the "gum beds" at Oil Springs, Ont., will be deposited; or, on a larger scale, extensive beds of asphaltum will remain, as in Santa Barbara and Los Angeles counties, Cal.; on the islands of Cuba and Trinidad, in the West Indies; in Egypt, Palestine, and other countries. The Egyptian asphalt has for centuries been famous for its useful qualities, and is extensively used in Europe for streets. California asphaltum also finds extensive use.

Let us now bring the facts together in a tabular exhibit:

CONSPECTUS OF THE GEOLOGY OF PETROLEUM.

	FORMATIONS.	SOURCE OF OIL.		OIL REGIONS.
	DRIFT GRAVEL (10)	(*c*)	*C.*	Oil Springs, Ont.
TERTIARY	SANDSTONES (9)		*J.*	Cal., in Los Angeles County, etc.
	Bituminous Shales (f)			
CARBONIFEROUS	COAL MEASURE SANDSTONES (8)	(*e*)	*I.*	West Va.; Southwest Pa.
	Coal Measure Shales (e)			
	COAL CONGLOMERATE (7)	(*d*) (*c*) (*b*)	*H.*	Southwest Pa.; W. Va.; Northeast Ky.
	Shales and Shaly Coals (d)			
	CARBONIFEROUS LIMESTONE (6)	(*c*)	*E.*	Glasgow region, Ky. (part.) Contiguous part of Tenn.
	WAVERLY SANDSTONE (5)	(*c*)	*G.*	Central O.; Venango Co., Pa.
	CHEMUNG SANDSTONE (4)	(*c*)	*F.*	Northwest Pa.; Southern N. Y.; Northeast O.
Hamilton	GENESEE SHALE (3)		*E.*	Glasgow region, Ky. (part.)
	Genesee Shale (c)			
	HAMILTON LIMESTONE (2)	(*b*)	*D.* *C.*	Bothwell, Ont. Enniskillen. Ont.
	Marcellus Shale (b)			
	Corniferous Limestone			Bituminous generally.
	Niagara Limestone			Bituminous frequently
Cincinnati	FISSURED SHALY LIMESTONE (1)	(*a*)	*B.* *A.*	Manitoulin Island. Burksville, Ky.
	Black Utica Shales (a)			

Here the various formations concerned are arranged in geological order. Those which serve as the source of petroleum in America are printed in *italics;* those which serve as reservoirs, in small capitals. The letters (*a*), (*b*), (*c*), etc., are used to designate sources; the numerals (1), (2), (3), etc., denote reservoirs, and the letters *A*, *B*, *C*, etc., indicate regions.

The foregoing facts are otherwise set forth graphically in the accompanying diagram, Fig. 111. Petroleum is known to exist to some extent in all formations from the Eozoic to recent deposits.

Other important localities of petroleum, besides those mentioned, are Baku, on the western border of the Caspian, in Georgia, Rangoon, Burmah, and the duchies of Parma and Modena, in

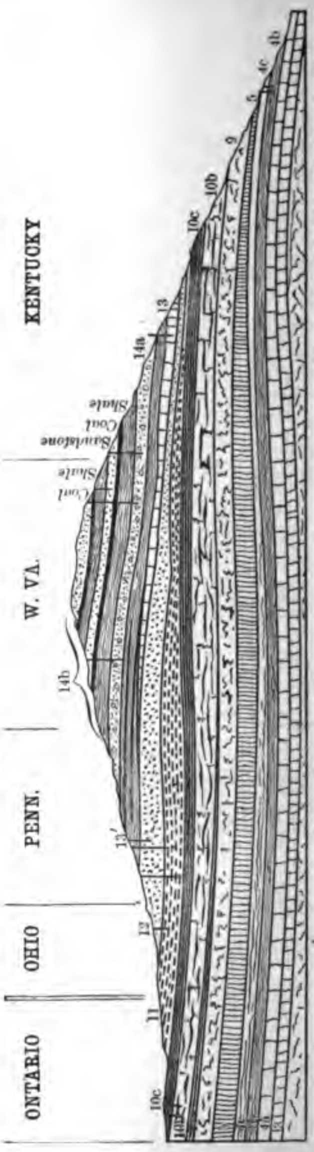


FIG. 111.—GEOLOGY OF PETROLEUM IN THE EASTERN UNITED STATES. IDEAL SECTION. 4*a*, Trenton *L.* 4*b*, Utica Shale. 4*c*, Hudson River Slate. 5, Niagara Group. 9, Corniferous Group. 10*a*, Marcellus Shale. 10*b*, Hamilton *L.* 10*c*, Genesee Shale. 11, Chemung. 12, Waverly. 13, Lower Carboniferous *L.* 13′, Lower Carboniferous Shale. 14*a*, Conglomerate. 14*b*, Coal Measures.

Italy. It is also very recently reported from Deli, on the east coast of Sumatra, one well yielding 270 barrels a day. The Baku petroleum occurs in a porous, argillaceous sandstone of Tertiary age. In the vicinity are hills of volcanic rocks, through which springs of the heavier sorts flow out. The Rangoon oil is obtained from wells sunk sixty feet in beds of sandy clay, which rest on sandstones and argillaceous slates. Under the slates is said to be "coal," but the strata are probably of Tertiary age, and the coal is likely to be an argillaceous lignite or a bituminous shale. In Los Angeles and neighboring counties, Cal., the yield from Tertiary strata was 5,000,000 gallons in 1882, and 262,000 barrels in 1884.

Illuminating oil may be obtained from all organic substances by distillation. Petroleum is probably derived from both animal and vegetable remains. That occurring in limestones may be of animal origin, but that derived from black shales more probably has a vegetable origin.

The production of natural gas in 1885 and subsequently has grown to a wonder not inferior to the yield of petroleum which began in 1859. It escapes from wells bored in certain districts, generally 1,500 to 2,000 feet deep. The gas is a varying mixture of light and heavy carburetted hydrogens — chiefly, however, marsh gas — and escapes generally under the very high pressure of 100 to 700 pounds to the square inch. In the vicinity of Pittsburgh, not less than 150,000,000 cubic feet were produced daily in the latter part of 1885, and 60,000,000 were already introduced into the city. Sixty-five to seventy millions were daily wasting in the Murraysville district alone. Gas fuel has already revolutionized the manufactures of the city. It is reported, also, that pipes are being laid for conveyance of the gas to Buffalo and Cleveland. Meantime, enormous supplies of gas have been reached in northern Ohio from wells which seem to penetrate the Cambrian. One is located at Cleveland. At Fremont, it is said, 2,000,000 feet were (in January, 1886) yielded daily. Gas and oil are reported at Lima, at the depth of 1,251 feet. The "Great Karg Well," at Findlay, Ohio, is reported (April, 1886) to yield 10,000,000 feet daily from a depth of 1,144 feet. The ignited jet ascends 115 feet.

It is impossible that such enormous supplies of oil or gas should continue many years. Reproduction is undoubtedly in progress, but it is comparatively slow. We are using and wasting the accumulations of millions of years.

EXERCISES.

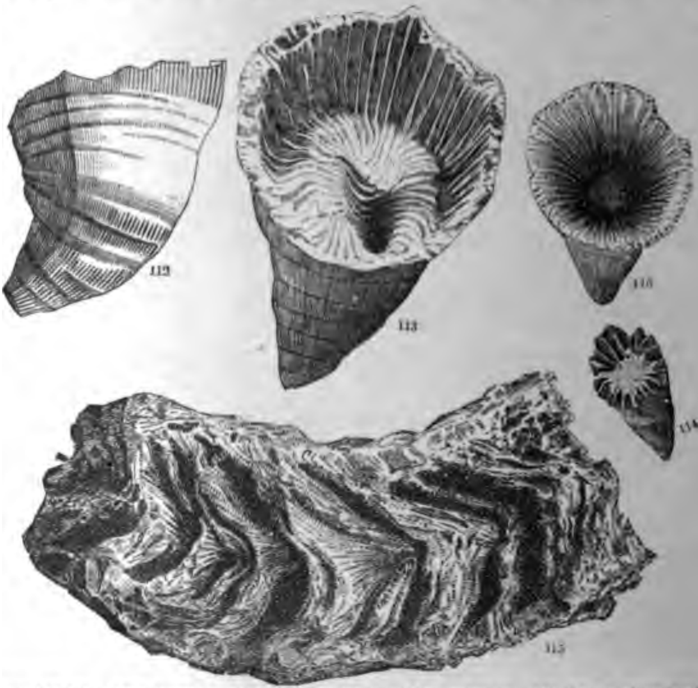
When black shale burns with a flame, why does it not crumble to ashes like coal? What causes the reddened appearance of burned shales? Name some localities where oil springs occur. Can you tell why Paint Creek, in Kentucky, is so named? Is the vicinity of an oil spring the best place to bore for oil? If not, why not? Does mineral pitch dissolve in water? What causes the durability of asphaltum when used for pavements? What are the characters of lubricating oil? Can you describe the odor of the Ontario oils? Why is kerosene sometimes called "coal oil"? What is Breckenridge oil? What sort of coal is found in Breckenridge county? How does it differ from a bituminous or carbonaceous shale? Would there be a good prospect of success in seeking an oil well at Ontonagon, Lake Superior? Look over this list of localities, and indicate, as nearly as you can, those most favorably situated for oil wells, and those least favorably situated: Potsdam, N. Y.; Hartford, Conn.; Waukesha, Wis.; Mobile, Ala.; Chattanooga, Tenn.; Binghamton, N. Y.; St. Clair, Mich.; Erie, Penn.; Wheeling, W. Va.; Frankfort, Ky.; Montreal, P. Q.: Sarnia, Ont. Have you carefully considered what formations underlie these places? Have you indicated the oil-producing formations under them? Have you indicated formations suited to serve as reservoirs? Some mineral "gum" (asphaltum) occurs on the surface west of Grand Traverse Bay, Mich.; explain how this happens. How do the formations underlying St. Clair, Mich., compare with those under Oil Springs, Ont.? If they are the same, why cannot oil be obtained at St. Clair? What would seem to be the source of the powerful gas wells in Knox county, Ohio? As 12,000 feet of gas are estimated to be equivalent in heating capacity to one ton of bituminous coal, how many tons are represented by a total supply at Pittsburgh of 60,000,000 feet? How many coal miners does this supply of gas represent?

STUDY XXX.—*Examination of Some Cup Corals.*

Rocks and minerals are not the only geological specimens brought to our very doors in the Drift. Every one living in the western states, or in southern Ontario, is acquainted with certain organic forms (compare Study XVIII) which the untaught farmers refer with amusing confidence to things familiar to them. Thus we have "petrified honeycomb," "petrified wasps' nests," "petrified horns," "petrified butterflies," "petrified snakes" — not to mention "petrified hands," "petrified feet," and other petrified things, which are nothing but curious results of the weathering of rocks. We must try to make some acquaintance with these objects. At present we will look into their structure, and hereafter we will ascertain what formations they are derived from. It is common to find a promiscuous assemblage of these forms gathered on some shelf or in some box, badly cared for, and yet too curious, and often too beautiful, to permit the intelligent owner to throw them away. Often he longs to know something about them; but there are really few available aids within his reach.

Now, let us look over such a collection. Most of these fossils are worn — some too much worn to possess value, but others showing at least some little part in a fine state of preservation. In fact, some of the finest specimens ever found come from the Drift deposits. Large and valuable collections may be gathered from this source, in any part of the region west of the Hudson River. Assorting these specimens according to such knowledge as we possess, we easily divide them into specimens which seem to be shells and specimens which seem to be corals, or which, at least, are not shells. Among those which appear to be corals we readily make again another distinction. Those which present any resemblance to honeycomb or wasps' nests may be separated from those which are more or less horn-shaped — that is, short, conical and curved, like a young steer's horn. In picking out all of this division, we must consider that most are somewhat broken and worn, and we must try to conceive the shape of the missing parts. We must also make allowance for some irregularities of form. These corals are not all shaped precisely like bullocks' horns, even when perfect. Sometimes they are rather long and cylindrical; sometimes they are suddenly bent one way or another; and often they swell out and contract at intervals. Sometimes the exterior appears to be covered by a skin; often this has been worn off, and we see, externally, white lines imbedded in the coral mass, and running from end to end. This is the division of the corals which we wish to study. These are cup corals. A group of them is shown in Figs. 112–116. These are several of the best preserved.

First, study their external characters. The whole specimen is sometimes called the *cell*. It is also known as *polypary*. You notice at the larger end, which we will call the upper end, a depression, giving the coral the appearance of a cup. This is called the *calyx*, or *cup* (plural, *cal'yces*), and this explains why these are called cup corals. (Figs. 113, 114, 116.) The adjective which expresses some relation to the cup is *calyc'inal*, as *calycinal extremity*. Sometimes we find a pit in the bottom of the cup on one or two sides, as in Fig. 113. This is a *fossa*, *fossette*, or *fovea*. The exterior of a perfect specimen is generally covered by a skin-like covering called *epi-the'ca*. This, in some species, is smooth, but more frequently it is transversely *wrinkled*. (Fig. 112.) Under the epitheca is the *wall*. Where the epitheca is wanting, or has been worn off, we often see



FIGS. 112-116.—CUP CORALS. 112, *Zaphrentis Prolifica*, exterior. 113, Same, showing the Cup. 114, *Amplexus Shumardi*, general view. 115, *Clisiophyllum Oneidaënse*, showing interior. 116, *Cyathophyllum Cornicula*.

numerous white lines running lengthwise of the coral (Fig. 124); these are *cos'tæ*, or ribs (adjective, *costal*). In the cup may be seen a set of radiating raised lines, which look like the upper edges of radial plates. These extend from the outer wall toward the centre. Different species differ greatly in the extent of their development. These are generally called *sep'ta* (singular, *sep-*

tum). We shall see that they run lengthwise toward the lower end of the polypary.

Next, let us study the interior. To do this we may make a transverse section — that is, a cut across the polypary at right angles with the axis or line through the middle, from end to end. You will be much interested in this work. Sometimes we find a specimen broken square across, but often we must break it. The surest way, to avoid spoiling the specimen, is first to file a groove around the fossil with a three-cornered, or, better, a "knife-edge," file. But you must select a calcareous specimen; a silicified one would ruin your file immediately. Then resting the coral on a solid support, like an anvil, if you have one, place the edge of a "cold chisel" in the groove, and strike a smart blow on it with a hammer or mallet. If the pene of your geological hammer is not very dull, you can use that as a cold chisel. Now grind one of the broken surfaces flat and smooth, and polish it. You may use first the smooth flat side of a grindstone; or you may use emery and water on a flat surface of lead, copper or iron. Next, you may polish the surface on a fine hone; or you may do it with emery flour on a piece of plate glass six or eight inches square. The finest polish may be produced with dry emery "slime" on a piece of buckskin tacked to a smooth board. When a transverse section of your cup coral is thus polished, it shows a beautiful internal structure which you can examine with a lens, and of which you may make drawings.

But it is possible to do even better than this. You may procure a very thin transverse slice — so thin that light passes through it, and the whole internal structure will be perfectly shown. File a deep groove around the specimen, a quarter of an inch back from the polished face, and cautiously chip off this thick slice. Attach it to a piece of thick glass, one or two inches square, by melting on the glass, over a lamp or a stove, some hardened Canada balsam, pressing the slice, polished side down, in the balsam, till the air bubbles are expelled. When cold and hard, grind the rough side as before, holding by means of the glass, until as thin as paper, or thinner if still too opaque, and polish the surface. Then soften the balsam and cautiously push the slice off into a few drops of softened or liquid balsam resting close by on a microscopic glass slide, taking care to exclude air from beneath the specimen. A microscopic slide is a piece of glass, one by three inches. Next, cover the slice with a drop of balsam, and put on a thin glass cover seven-eighths of an inch square, which may be held down by means of a spring "clothes-pin," until the balsam is hard. If the balsam was liquid before warming, gentle heat will now be required to harden it. Finally, superfluous balsam should be removed with a knife, and the final cleaning of the surfaces of the glass effected with spirits of turpentine and bits of cotton cloth. There is nothing in all this beyond the skill or resources of any intelligent student; but the result will be found both gratifying and instructive. Thin slices of rocks and minerals may be similarly prepared; but silicious specimens make more laborious manipulation, and it is best to begin with thin chips struck off with a hammer. If thin slices of corals are not made, many polished surfaces should be prepared.

Now, what does a thin section of our cup coral reveal? Here it is, in Fig. 117. You notice, first, the outer *wall*. Next, you see a system of radiated structures, extending from the wall toward the centre. Make a transverse section at any distance from the bottom, and similar structures will be seen. These, then, are the *septa* before noticed in the cup. They are longitudinal radiating plates. Some of the septa, as you perceive, extend well toward the centre, and in this species are a little twisted together. Some extend but a part of the distance. This coral which is shown in Fig. 117 has also a fovea in the cup—though your specimen may not be sufficiently perfect to show it.

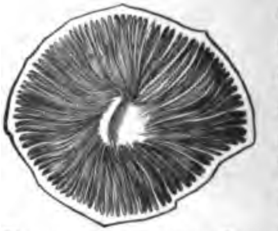


Fig. 117.—TRANSVERSE SECTION OF A CUP CORAL (*Zaphrentis prolifica*), SHOWING THE SEPTA.

Now, think over the characters just mentioned. You may remember that this assemblage of characters forms the genus called *Zaphrentis.*

Let us take another, and different, cup coral, and prepare a longitudinal section. This may be done in a manner entirely similar to that before described. Grooves will be filed lengthwise of the specimen along opposite sides. Then, after polishing one of the halves and attaching to the glass, it may be best to grind away the whole half down to a thin slice. Sometimes we use a large file for coarse work. Here is the result, in Fig. 118. The outer wall is, of course, shown as before. If the section is precisely central, none of the septa will be cut, and hence none will be seen. Here are no septa shown; but some transverse structures are seen. These are called *floors* or *tabulæ,* for they are thin, more or less flat plates. By some they are called *diaphragms* and *septa* —but we will not so use these terms. Notice that in this specimen the tabulæ are broad and conspicuous, extending almost from wall to wall of the body cavity. Here, in Fig. 119, is a cross section of a specimen of the same species. Notice particularly that the septa are very narrow. Bear in mind this combination of characters. It is known as the genus *Amplexus.*

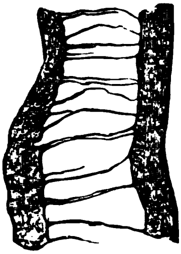


FIG. 118.—LONGITUDINAL SECTION OF A CUP CORAL (*Amplexus Yandelli*), SHOWING THE TABULÆ. Defects in tabulæ result from fossilization.

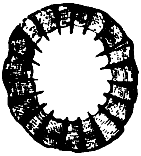


FIG. 119.

CROSS SECTION OF THE SAME SPECIES AS IN FIG. 118, SHOWING VERY NARROW SEPTA. See also Fig. 115.

Now we shall find no difficulty in preparing transverse and longitudinal sections of many different specimens. In Figs. 120 and 121 we have sections of a form which shows septa not reaching the centre, and tabulæ occupying only the middle of the cavity, stretching from the inner margins of the septa on one side to the inner margins on the other. This portion of the interior is known as the central part of the *visceral cavity,* or simply as the visceral cavity.

But we notice in the section (Fig. 120) some delicate structures passing from septum to septum, in the region outside of the central part of the visceral cavity, and dividing it into small cell-like compartments. This is known as the *peripheral region*, and these delicate dividing lines are sections of *dissepiments*. These run obliquely downward and inward, as shown in Fig. 121, and seem to be modifications of tabulæ. You will notice particularly what characters are associated together in this form. They constitute the genus *Cyathophyllum*.

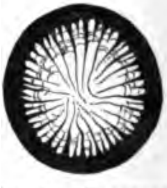


FIG. 120.—TRANSVERSE SECTION OF ANOTHER CUP CORAL (*Cyathophyllum*), SHOWING SEPTA, CENTRAL AREA, AND DISSEPIMENTS IN THE PERIPHERAL REGION. (Diagram.)

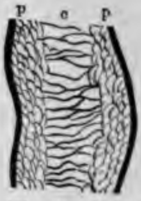


FIG. 121.—LONGITUDINAL SECTION OF A SPECIMEN OF THE SAME SPECIES AS IN FIG. 120 (*Cyathophyllum*).

Now let us pause to gather these few results together, and make some tentative generalizations. The fundamental structures of cup corals, as we have seen, belong to three categories: (1) The *mural* system, or outer wall; (2) the *septal* system, or radiating vertical plates or lamellæ; (3) the *tabular* system, or transverse plates. Let us conceive these three systems to be essential structures in every cup coral, and to be always present in some state of development, or under some modification; and let us conceive a tabula to be, theoretically, a floor extending across the whole body cavity, from wall to wall. Then we shall have some interesting studies in tracing the *homologies* of these parts in different genera—that is, in determining what structures should be referred to septa and what to tabulæ, and what is the nature of the modification undergone by these categories respectively in any particular case. If these assumptions are not in accordance with fact, we shall be unable to interpret cup-coral structures on the basis of them.

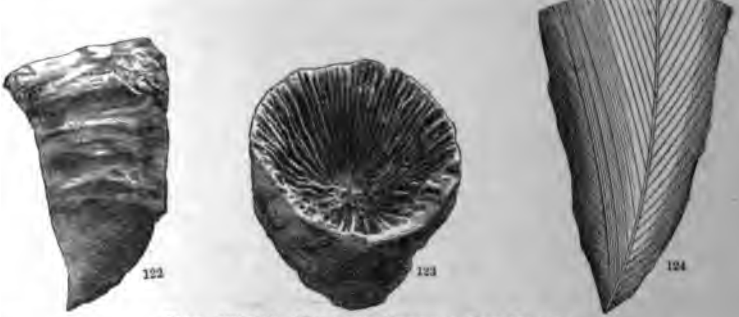
We must be prepared to find each of these categories developed to a complete extent, to a partial extent, or only to an incipient extent; or even, in some cases, they may be obsolete, that is, only *potentially* present. If the tabulæ extend, under *any* modification, quite across the body cavity, they must intercept all the septa, so that the wedge-shaped space between each two septa will be cut into a number of narrow, wedge-shaped spaces arranged in a vertical series. If the outer parts of the tabulæ are curved upward, instead of continuing horizontal, then, on a transverse section like Fig. 120, they will be cut, and their cut edges will be seen exposed. From this will result the appearance of cellular tissue seen in the peripheral region of the *Cyathophyllum*, Fig. 120. So we may anticipate other modifications of the several parts.

EXERCISES.

If your place of study is anywhere west of the Hudson River, the Adirondacs and the Appalachians, and east of the Missouri River, and not on a prairie-covered region, you should make a collection of Drift fossils. In this is included nearly the whole valley of the St. Lawrence River and the peninsula of western Ontario; but we exclude the Eozoic regions of northern Michigan, Wisconsin, and Minnesota, and southern Missouri. Of course, fossils found *in place* (in the rock) must be had when obtainable, though really Drift fossils often show structures more perfectly than these. Have you collected any fossils? Have you attempted to arrange them according to their forms and characters? Take this lot of fossils before us and arrange them as completely as possible. Point out the cup corals. Take any specimen and state what part is broken away. What has been the effect of wear on it? Is it silicified or calcareous? Show where a transverse section might be cut. Show the longitudinal section. Does this specimen show the septa? Does it show any tabulæ? Is the epitheca present? Does the peripheral part contain cellular structure? What genus has this character? Do the septa extend to the centre? Take other specimens and answer the same questions in reference to them.

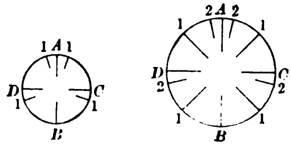
STUDY XXXI.—*Further Examination of Cup Corals.*

Let us seek further facts by examining a genus of cup corals known as *Streptelasma.* In Fig. 122 we have a view of the usual appearance of the exterior, and Fig. 123 shows the cup with a fovea on one side, and a series of septa reaching the centre with somewhat of a twist. There is no appearance of cellular tissue in the peripheral part, and there is no indication of tabulæ except in the partially cellular mass in the centre, which, in some cases, we find raised into a dome-like elevation. This central mass may be conceived as resulting from the intersections and slight twisting of tabulæ and septa. In Fig. 124 we find an interesting exhibition of an arrangement of the septa often called "*feather-form*" or *pinnate.* The lines show where the septa come to the periphery, the external wall in this case being deficient.



FIGS. 122-124.—VIEWS OF SEVERAL CUP CORALS.
122. *Streptelasma corniculum*, exterior. 123. Same, showing Cup. 124. Same, showing arrangement of Septa on the exterior.

This example will serve to show the mode of increase of the septa. A section across Fig. 124 close to the lower end would reveal only four septa. These are the *primary septa, A, B, C, D*, Fig. 125. Of these, *A* and *C* are shown in Fig. 124. *A* is the *chief septum*, *B* the *antiseptum*, and *C* and *D* the *lateral septa.* With the growth of the coral, four additional septa appear, in the places marked 1, 1, 1, 1, in Fig. 125. Two of these are parallel with *B*, one parallel with *C*, and one with *D*. Of these four additional septa, the one parallel with *C* is shown in Fig. 124. With further growth, these septa elongate, and others appear parallel with them, as may be seen at 2, 2, 2, 2, Fig. 126, and in part, also, in Fig. 124. Thus, as growth proceeds, and the circumference of the cup increases, the distance of the septa in the cup appears to remain the same. Now let us conceive the exterior of the specimen, Fig. 124, to be a skin, and let us slit down along the primary septa, *A*, *B*, *C*, *D*, to the apex. Then, removing the skin and spreading it on a flat surface, we shall see the plan of the septa and their mode of growth. The appearance will be somewhat as shown in Fig. 127. Here *A*, *B*, *C*, and *D* indicate the places of the primary septa, as before. It is seen that the whole system is divided into four quadrants or *fascicles* of septa — the two fascicles on the right of the median line *A B* being symmetrical with the two fascicles on the left. The plan of the septa is, therefore, fundamentally bilateral. The radiality is subordinate — and this, it may be said, can be shown of every other so-called "radiate" animal. The break or discontinuity of the septa along the primary septum *A* is called the *apertural gap*. The one opposite, along *B*, is the *central gap;* the other two are the *lateral gaps.* The place of the principal fovea in the cup is at *A*. Giving attention to each quadrantal fascicle in succession, it is easy to perceive the succession of the septa. The older ones are the longer, because they have been growing a longer period. The shorter septa are the newer ones. The succession is indicated by the numerals 1, 2, 3, 4, 5, 6, etc. Had the cell grown further, the additional septa would have been introduced at *O*, *O*, *O*, *O*. Since four is the number of primary septa in the



FIGS. 125, 126.—PRIMITIVE SEPTA OF A CUP CORAL (MUCH ENLARGED).

125. The Four Primary Septa, *A*, *B*, *C*, *D*, with the First Accessory Septa, 1, 1, 1, 1.

126. The Second Set of Accessory Septa, 2, 2, 2, 2.

The numerical designation of Septa is the same as in Fig. 127.

cup corals, they are also known as TETRACORALLA. By Milne-Edwards they were styled *Rugosa.*

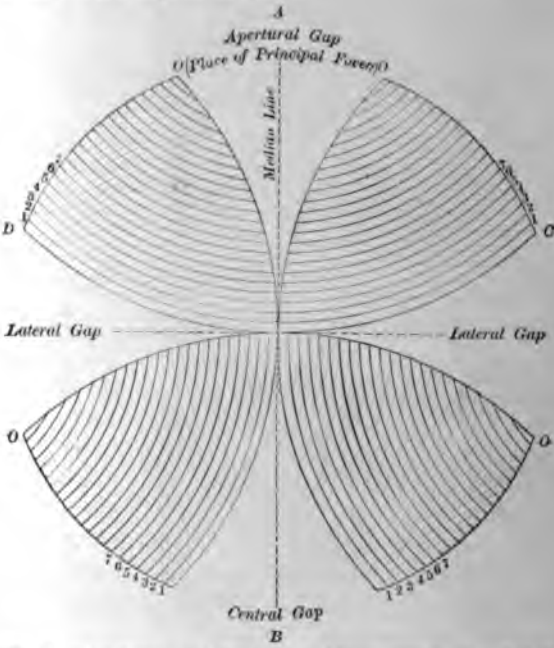


FIG. 127.—PLAN OF SEPTA AND BILATERAL ARRANGEMENT OF A CUP CORAL.
The external walls of the the four Fascicles of Septa are developed or spread out into one plane. The additions to the number of Septa take place at *O, O, O, O.* All the Septa increase in length.

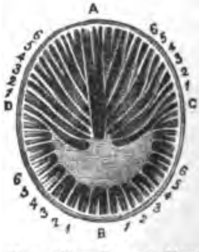


FIG. 128.—CUP OF *Menophyllum*, E & H.

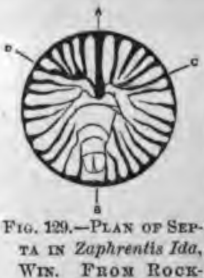


FIG. 129.—PLAN OF SEPTA IN *Zaphrentis Ida*, WIN. FROM ROCKFORD, IND. (From Nature.)

After examining the cups of numerous cup corals, we shall find that the plan of septa above described is but imperfectly shown in the cup; yet indications of it almost always exist. A very clear illustration of it is given in Fig. 128.

In some of the western states, and even western New York and Ontario, we can hardly make a collection from the Drift without finding included some corals of the species represented in Figs. 130, 131. Here we have a widely open cup, showing septa almost strictly radiate, but with the alternate septa shorter than the others. It was probably this beautifully rayed appearance which suggested to Milne-Edwards the name *Heliophyllum*. The transverse section, Fig. 132, shows a vesicular tissue in the peripheral region, and this is nearly all the evidence of the presence of a tabular system. Both figures, however, reveal certain appendages to the septa which are conceived to be characteristic of this genus, though, in fact, we find them in several other genera. A longitudinal section, Fig. 133, shows them to be sharply raised, opposite pairs of *cari'næ*, or ridges, running along the lateral surfaces of the septa, and curving in such a way as to outcrop in the cup. The carinæ are seen in Fig. 133, in places *C*, *C*, where the thin section cuts obliquely across a septum.

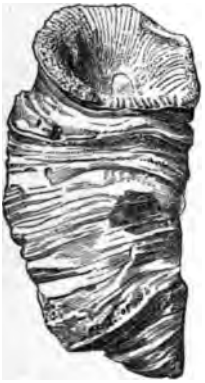


FIG. 130.—*Heliophyllum Halli*, HAMILTON GROUP, WIDDER, ONT. (From Nature.)

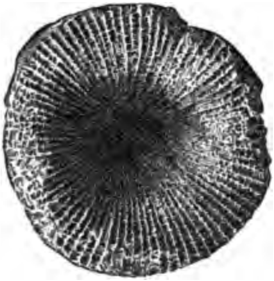


FIG. 131.—SAME, VIEW OF THE CUP.

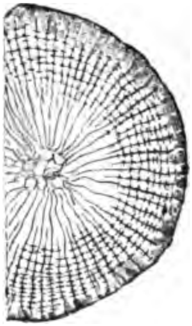


FIG. 132.—PART OF TRANSVERSE SECTION OF *Heliophyllum Halli*.

An equally common form of cup coral is the *Cystiphyllum Americanum*, Fig. 134. The cup presents a surface covered with blister-like elevations; and sections in Figs. 135, 136 and

137 show the whole interior occupied by a coarse vesicular tissue, without characteristic septa or tabulæ. We may suppose the mutual intersections of these structures have resulted in such mutual displacement and distortion that the typically wedge-form compartments have become mere vesicles.

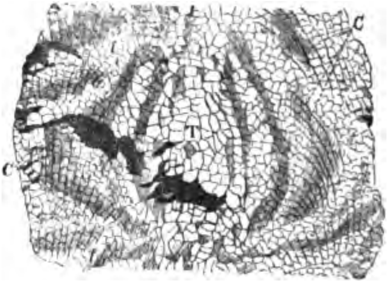


FIG. 133.—LONGITUDINAL SECTION OF *Heliophyllum Halli*, SHOWING THE CARINÆ ON THE SEPTA. (From Nature.) *C*, *C*, Carinæ cut lengthwise, the oblique sections of the Septa giving the clouded patches. *T*, coarse cellular tissue of central part of visceral cavity. *t*, fine cellular tissue of peripheral part. (The black blotches are mere opaque rock material.

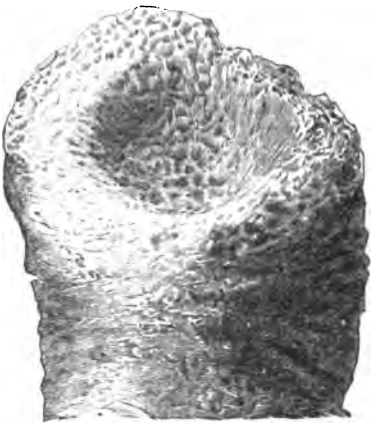


FIG. 134.—*Cystiphyllum Americanum*. UPPER EXTREMITY OF A LARGE SPECIMEN. (From Nature.)

All the cup corals thus far examined are ***simple***. That is, each specimen is the work of a single individual *polyp*. But many cup corals are compound, and we find them so in the Drift. Throughout the Northwest, one of the very commonest and most beautiful of these is *Acervularia Davidsoni* (Figs. 138, 139). Visitors to Petoskey on Little Traverse Bay are made very familiar with this coral through the polished specimens which are offered for sale. But it is found there imbedded in its natural formation. *Acervularia* forms aggregations in elegant spheroidal and cake-like masses. Each mass is a group of small, generally crowded, and polygonal cells, each of which is a real cup coral. They are mostly six-sided by mutual pressure, but sometimes a tube stands sufficiently isolated to retain its fundamental cylindrical form. The common wall between contiguous cells is delicately wavy. The centre of each cup is abruptly sunken. The septa of first order reach the centre; those of the second order reach only to the central pit. Indications of carinæ are seen on the septa in the peripheral region. In the cross-section, Fig. 139, the characters of the limiting wall and the septa are still more clearly shown. It appears from this that carinæ are not exclusively characteristic of *Heliophyllum;* but they make here a different group of characters from the group which constitutes a *Cyathophyllum.*

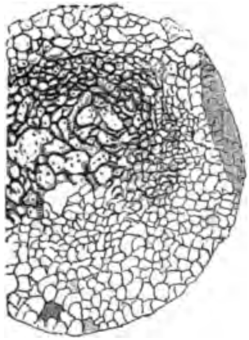


FIG. 135. — PART OF TRANSVERSE SECTION OF *Cystiphyllum Americanum.* (From Nature.)

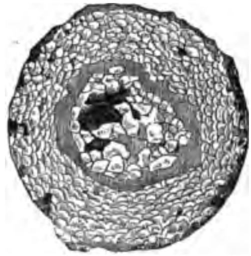


FIG 136. — TRANSVERSE SECTION OF A *Cystiphyllum,* SHOWING A DENSE ZONE AROUND THE CENTRAL PART, AND COARSER TISSUE IN THE CENTRE. (From Nature.)

In Fig. 140 we have another compound cup coral. Each cell or tube is by itself nearly a *Cyathophyllum.* That is, it shows, in longitudinal section, some very distinct though irregular tabulæ in the central portion, and an elegant vesicular tissue in the peripheral portion. But the tabulæ rise in a conical elevation in the centre of the cup, constituting the distinct genus *Lithostrotion.*

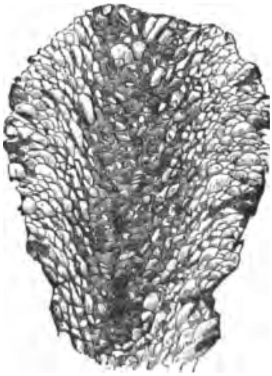


FIG. 137. — LONGITUDINAL SECTION OF *Cystiphyllum Americanum.* (From Nature.)

Still another elegant compound cup coral appears in Figs. 141, 142 and 143. The genus *Diphyphyllum* is characterized by the presence of an inner wall, which is here very distinctly shown. In addition, notice the delicate equidistant tabulæ across the small inner tube, and the fine vesicular tissue between it and the outer wall. The septa are alternately wide and narrow, the former reaching the inner wall.

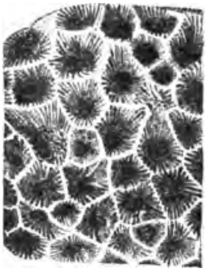


FIG. 138. — *Acervularia Davidsoni.* VIEW OF A CLUSTER OF CUPS.

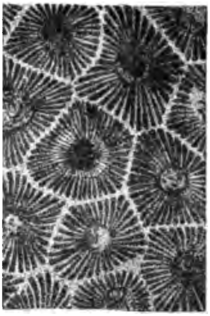


FIG. 139. — TRANSVERSE SECTION OF *Acervularia Davidsoni.* LARGER CELLS.

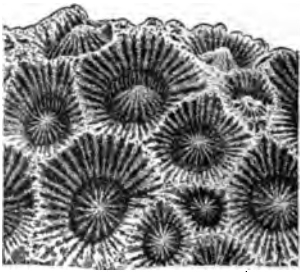
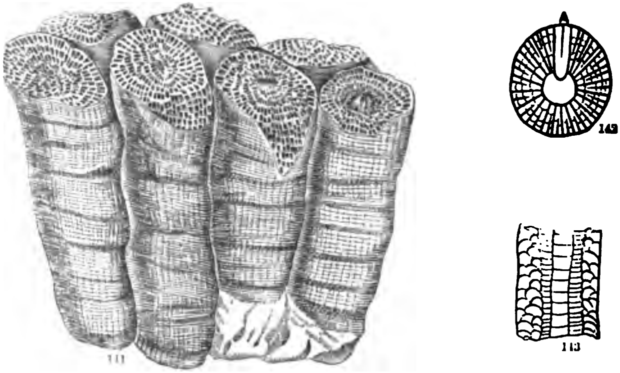


FIG. 140.—*Lithostrotion Canadense.* CARBONIFEROUS LIMESTONE OF MICHIGAN. (From Nature.)

The study of these corals is very fascinating; but we have pursued the subject quite far enough for an elementary course. In an advanced course, we shall resume the subject.



FIGS. 141, 142, 143.—*Diphyphyllum Archiaci.* (Billings.) HAMILTON GROUP. (From Nature.) 141, General View. 142, Transverse Section. Showing Double Wall, Septa, Primary Septum in a Fovea. 143, Longitudinal Section. Showing Double Wall, Central Tabulæ, and two sorts of Peripheral Tissue.

From the details enumerated, let us now gather together definitions of the different genera illustrated:

Amplexus. Simple, subcylindrical, narrowed toward the lower extremity, covered with epitheca. Septa slender, very narrow, equal, the chief septum in a fovea. Tabulæ horizontal, strong, mostly complete, closing the bottom of the cup.

Zaphrentis. Simple, horn-shaped or top-shaped, with epitheca. Cup deep, with a distinct fovea. Septa well developed, reaching the centre, more or less distinctly pinnate. Tabulæ also well developed, and reaching to the wall. In the peripheral region sometimes a little coarse vesicular tissue.

Streptelasma. Simple, conical, often curved, with epitheca. Septa radiate in the cup, unequally broad; the broader set somewhat twisted together in the centre, and forming, with the modified tabulæ, a vesicular eminence. Chief septum and lateral septa distinctly shown externally, as also the pinnately arranged later septa. Tabulæ completely developed.

Cyathophyllum. Simple or compound, with epitheca. Tabulæ in the middle of the visceral cavity, cellular tissue in the peripheral part. Septa numerous, regularly radiate, reaching the centre, and sometimes twisted there into a feeble elevation.

Lithostrotion. A compound *Cyathophyllum*, having the central vesicular tissue condensed into a column which rises in the deep cup as a solid striated cone. Tubes striated externally, sometimes isolated and cylindrical.

Heliophyllum. Simple, top-shaped, seldom compound. Septa numerous, perfectly developed, their sides decorated with carinæ, or raised lines running downward and inward, and arranged in pairs on opposite sides. Irregular tabulæ in the central part, cellular tissue in the peripheral. A *Cyathophyllum*, with carinæ.

Cystiphyllum. Simple or compound, with epitheca. Exterior deeply wrinkled, and the form often elongate, geniculate, or irregular. Septa and tabulæ extremely modified, their normal forms sometimes not appearing, a cellular tissue filling the whole visceral cavity, the cells mostly somewhat crescentic in form, and generally arranged in distinguishable layers from below upward.

ACERVULARIA. Compound, stems sub-parallel, approximated, often crowded and hexagonal. Cup with an abrupt pit in the centre. Septa well developed, extending alternately to the centre and to the pit. The central part of the visceral cavity with variously shaped tabulæ, the peripheral with cellular tissue.

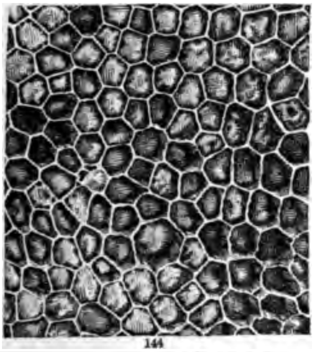
DIPHYPHYLLUM. Compound, consisting of generally slender, cylindrical, epitheca-covered cells, furnished with an interior wall distant from the outer wall. Septa numerous, reaching the inner wall. In the interior, a series of tabulæ; in the peripheral part, cellular tissue.

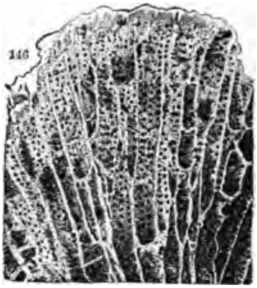
EXERCISES.

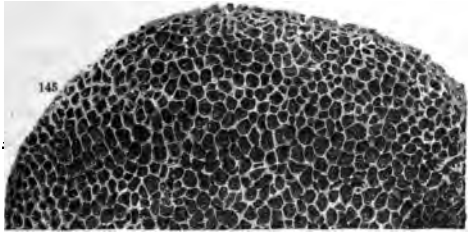
Make some polished sections of cup corals. In what respect are *Streptelasma* and *Zaphrentis* alike? In what respect unlike? How does *Zaphrentis* differ from *Cyathophyllum?* How does *Heliophyllum* differ from *Cyathophyllum?* Copy Fig. 127 on a piece of paper, then cut out the four quadrantal fascicles, leaving them connected at the centre, and fold them together like a half ball-cover; do you find an appearance like Fig. 124? Copy Fig. 132. Copy Fig. 139. How does *Acervularia* differ from *Diphyphyllum?* Have you been able to identify any cup coral found by yourself? Have you ever collected fossils except from the Drift? Do you know any locality at which fossils may be obtained from the rocks? Have you ever seen *Acervularia* at Petoskey? Have you polished any coral sections with your own hands? If so, let us see them. To what genera do they belong? Make drawings of some of your polished sections of cup corals. Select one or two of your most perfect specimens of cup corals and draw them.

STUDY XXXII.—*Examination of Some Tabulate Corals.*

Our collection of Drift corals was divided, in a former study, into two lots. The cup corals, or *Rugosa*, we have now learned how to study. The other lot, or those commonly called "petrified honeycomb," we must next take up and examine. These are quite as common as the rugose corals; and it may as well be stated at once that the proper designation of the group is TABULATA, or HEXACORALLA. From almost any neighborhood within the area before defined we may pick up specimens either identical with those delineated here, in Figs. 144-148, or at least generically identical with them.







Figs. 144-148.—Various Species of Favosites.
(From Nature.)
144, F. *favosus* Gf., showing hexagonal cells, septal rudiments, and tabulæ. 145. F. *Alpenensis* Win., showing angular apertures. 146, F. *tuberosus* Rom., showing pores. 147, F. *nitella* Win., with cells small. 148, F. *clausus* Rom., branched.

Beginning with the one represented by Fig. 144, we see a large number of tube ends closely crowded together, and pressed into hexagonal forms. So far as we can see, any two walls in contact are blended into a single common wall; but we shall have to examine more closely in a thin section. Some of the cells show strong tabulæ crossing from side to side. In some the tabulæ near the aperture have been removed, and in others no tabulæ are in sight. But do we discover any septa? There are none well characterized; but we plainly see a number of point-like depressions or indentations around the border of each tabula. Close inspection shows that these alternate with small projections from the inner walls of the cells, and these projections extend, as raised bands or ridges, lengthwise of the cells. Fig. 149 is a view of another specimen, showing this character. The raised bands or lines are twelve in number, and are separated by twelve longitudinal furrows. These raised bands appear like the stumps of septa, and the constancy of their number confirms this interpretation.

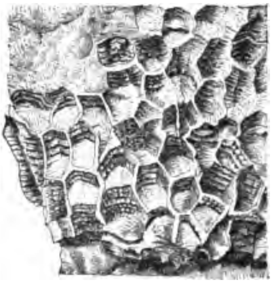


FIG. 149.—FAVOSITES FAVOSUS, SHOWING LONGITUDINAL LINES WITHIN THE CELLS: THESE REPRESENT SEPTA. (From Nature.)

If we turn our attention to the specimen shown in Fig. 145—*Favosites Alpenensis*, Winchell (afterward described by Rominger as *F. Hamiltonensis*)—we perceive that it is part of an elongated, rudely cylindrical, or tuberose mass, composed of small tubes, which rise from a common central axis, at a small angle, and, after continuing a certain distance, curve toward the surface of the mass, and present there their terminations or *mouths*. These tubes, throughout their whole length, are crossed by delicate transverse plates, which can be nothing but tabulæ. Hence, they are of the same nature as those seen in the mouths of the tubes of Fig. 144. Some of these tabulæ extend quite across; but some of them join the neighboring ones above or below, and hence are *incomplete*; and some, after touching their neighbors, continue separately. The tabulæ toward the outer ends of the tubes become quite crowded. We notice, also, a system of branching among these tubes. Many tubes do not originate at the centre, but start from a point in the wall between two tubes, giving the wall an appearance as if split, and thus suggesting that the wall is really double. It ought to be double, if formed by the union of the two walls of the two contiguous cells. This mode of introduction of new cells is called *lateral* *gemmation*, or budding from the side. We cannot see here the longitudinal bands and furrows which represent septa. Fig. 150, however, is a thin section of a small globular mass of this species. As the tubules radiate from a centre, the section, in passing near the centre, is transverse to the central tubules, and longitudinal to those near the exterior. Now, besides the conspicuous tabulæ, we can see here the longitudinal raised lines shown in section, and projecting like spines in the central tubules; and we see, also, a few pores, and a light line along the middle of the common wall in the longitudinal sections, proving plainly their double character. [Pores not engraved.]

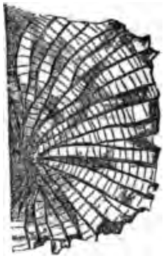


FIG. 150.—THIN SLICE OF *Favosites Alpenensis*. SHOWING TABULÆ, LONGITUDINAL MURAL STRIÆ, (but badly), DOUBLE WALLS, AND LATERAL BUDDING.

Now, if we take the specimen represented by Fig. 146, we notice, also, a series of slightly divergent tubes, but with only occasional tabulæ. As in some places they stand close together, it is probable that most of the tabulæ once present have been removed. We see nothing different in the nature of the walls, and notice also the evidences of lateral gemmation. But there is one striking character not before clearly seen. The vertical walls are perforated with numerous pores — also sparingly detected in Fig. 150. These are arranged mostly in two longitudinal series on each side, but the number of series depends on the width of the side. These pores establish complete communication between contiguous cells, as is shown in places where the light passes through.

Fig. 147 illustrates a more delicate structure, globoid in form, with small cells radiating from a centre. But a thin section, Fig. 151, shows tabulæ and pores quite like those in the other specimens. The apertures of some of the cells incline to be round. There is a type of this group having quite circular cell sections, and it is very

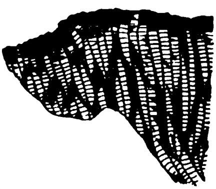


FIG. 151.—THIN SECTION OF *Favosites nitella*. ×4. SHOWING TABULÆ.

abundant throughout the Northwest. A group of the cell mouths is shown in Fig. 152. Here are two sorts of mouths. First, larger, circular mouths, about one millimeter wide, and quite separate from each other; second, small subangular mouths, about one-third the size of the others, standing close together, and forming a mass in which the larger cells are imbedded. If we make a vertical section, we shall see that both the large and small cells are supplied with tabulæ. We shall also perceive communicating pores. But there are no longitudinal grooves, and hence no indications of septa. In spite of the divergences of this type, we feel constrained to unite it with the other specimens having numerous tabulæ and connecting pores. These all belong to the great and important genus known as *Favosi'tes* (name from *favus*, a honeycomb, and the conventional termination *ites*).

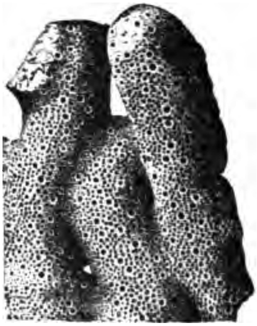


Fig. 152.—*Favosites Canadensis*, Bill. Showing Tubules of Two Sizes.

A form slightly different from any of these is also found quite frequently in the Drift of New York, Ontario, and the Northwest, as also, of course, in the rocks of certain formations. This is a rounded, depressed, cake-like mass, composed of numerous flattened tubes radiating from a basal point (not seen in Figs. 153, 154), reaching the surface at oblique angles, and opening in crescentically three-angled mouths — in other words, mouths like small spherical triangles. A section parallel to the tube lengths shows the tube walls longitudinally grooved or striated, and perforated with large pores situated on or near the two lateral edges. It shows also a series of remote, irregular tabulæ, and also some longitudinal crests or rows of spinulose projections, which are the homologues of

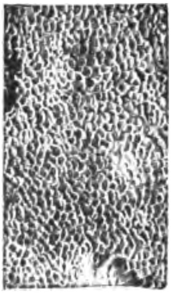


Fig. 153. — *Alveolites Goldfussi*, Bill.

septa. This is, therefore, fundamentally similar to *Favosites*, and belongs in the same *Family;* but, in consequence of the peculiar form of the tubes and tube mouths, and the positions of the pores, it is set down as a different genus, *Alveolites* (*alveolus*, a pit, and *ites*, as before).

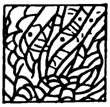


FIG. 154. SECTION OF *Alveolites Goldfussi.* SHOWING TABULÆ AND PORES.

Another form of this family is *Limaria* (perhaps from *limarius*, pertaining to slime or sediment). The surface of a specimen is shown in Fig. 155. It looks much like a small-celled but thick-walled *Favosites.* The apertures are compressed, and open obliquely to the surface. On the outer side, the lip bears two teeth projecting into the cavity; and on the inner side a single tooth projecting between the two outer ones (Fig. 156). A longitudinal section shows that the tubes are connected by lateral pores, and intersected by transverse tabulæ. The tabulæ are mostly wanting in the thick-walled portions of the tubes. This you perceive only differs from *Alveolites* in less compressed tubes, thicker walls, and fewer longitudinal crests. There is another genus, *Cladopora* (κλάδος, a branch, and πόρα, a pore, conventional name for certain corals), which only differs from *Limaria* in having no tooth-like projections in the apertures, and smooth, instead of crested, tube interiors. Tabulæ exist, but they are rarely seen, the tubes being generally open from end to end. Even longitudinal furrows, the vanishing indications of the septal system, are occasionally seen, and are to be regarded as potentially present. Lateral pores in the walls are also present. The species shown in Fig. 157 is branching and *reticulating.* Other species, like *Cladopora Rœmeri*, Fig. 158, are simply branched,

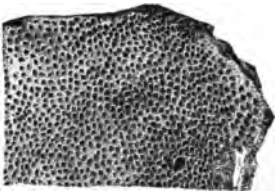


FIG. 155. *Limaria crassa*, RÖM.

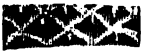


FIG. 156. MOUTH AND TEETH OF *Limaria crassa*. × 7. (In the specimen figured only one tooth is seen. The opposite two are generally inconspicuous.)

and still others form flat, leaf-like expansions. It would be interesting to extend the study of this group of forms, but we fear it would occupy an undue proportion of the student's time. The distinctive characters of this order of fossils have been shown, as also the method of investigating them. It appears that the septal system is feebly developed, but that the tabular system is generally conspicuous. For this reason they were named by Milne-Edwards TABULATA, or Tabulate Corals. We have seen also that the furrows and ridges which represent the septal system are twelve in number. If we should examine all the genera of this group, we would find some with six more or less complete septa. So the number in all cases is a multiple of six. As the number among the Cup Corals is a multiple of four, and they have hence been by Haeckel styled TETRACORALLA, so this Order has been by the same designated HEXACORALLA.

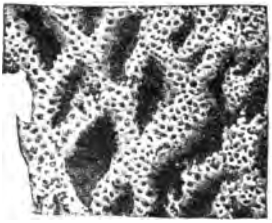


FIG. 157.
Cladopora laqueata, ROM.

Let us now bring together the characters of those genera of *Favositidæ* which have been illustrated:

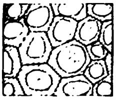


FIG. 158.
THIN SLICE OF *Cladopora Romeri*, BILL. SHOWING THICKENED DOUBLE WALLS AND DELICATE *Trabecular* STRUCTURES (LIKE SPIDER LINES) WITHIN THE CELLS. × 7.

FAVOSITES. Polypary, compound, massive (globoid, tuberose, pyriform, or elongate), flattened, or branching, composed of tubes which are generally crowded and hexagonal, but sometimes cylindrical, variable in diameter in the same species, and opening perpendicularly to the surface. Tabulæ generally numerous and conspicuous, in some species irregular or incomplete. Septa represented by twelve longitudinal furrows and alternating ridges, which are in some species crowned with spinules in one or more series. Walls perforated by pores in one, two, or more vertical rows on each side, but very different in number in different species.

ALVEOLITES. Polypary massive, convex, or flattened, often laminar or branched. Constituent tubules flattened and closely appressed, opening obliquely at the surface with a triangular orifice bounded by three curved lines. Septa represented by longitudinal furrows. Tabulæ more remote and irregular than in FAVOSITES. Pores very large on the two lateral edges of the compressed tubes.

LIMARIA. Small, branching stems or laminar expansions, composed of thick-walled, conico-cylindrical tubules, with compressed orifices opening obliquely to the surface, having a lip bearing two tooth-like projections on one side and one on the opposite. Septa feebly represented by three longitudinal crests on the walls. Tabulæ restricted to thinner portions of the tubules. Connecting pores present.

CLADOPORA. Ramose, often reticulating stems or laminar expansions — often these different forms in the same individual. Composed of thick-walled, conical tubules, opening obliquely to the surface, and having dilated orifices. Tubules laterally connected by pores. Tabulæ very rarely seen. Longitudinal furrows mostly obsolete, but occasionally discernible.

EXERCISES.

Point out several Tabulate Corals. Are they simple or compound? Are they calcareous or silicified? Were they obtained from the Drift or from strata in place? Are they nearly perfect? Indicate places where defects exist. Are they worn like Drift pebbles? Point out some fracture which passes between two tubules, if you can. Point out some fracture which passes through a tubule. Does this reveal the interior of the tubule? What structures are there revealed? Point out tabulæ, if present. Point out longitudinal furrows on the walls. What do these represent? Point out pores, if present. Are they scattered or numerous? In how many rows do they exist on each side? To what genus does this specimen belong? Do the mouths open vertically or obliquely? What is the form of the tube section? Make a drawing of a small portion of the specimen. Make an enlarged drawing of two or three tubules, with all the details. Pick out a *Favosites* with cylindrical tubules. What was the form of the specimen when entire? Explain how it differs from the last specimen. How can you most easily detect *Alveolites* from external characters? Which two of the four genera illustrated are least distinguishable from external characters? Which two have thickest walls?

STUDY XXXIII — *Examination of Some Brachiopods.*

Of the numerous fossils which any person may collect from the Drift, a large proportion appear to be ***bivalve*** shells — that is, shells composed of two pieces intended to open and close by a hinge, like a river mussel. Among bivalves, it is extremely easy to make a distinction based on the external form of the shell. Yet it is a distinction of very fundamental value, since it separates two *Classes* of Molluscs.

To begin with, we will take the shell of a common river mussel, Fig. 159, the hinge side up. The most prominent part, *a*, is called the *beak*. Now, any observing boy has seen the river mussel in the act of locomotion. It raises itself on edge, somewhat inclined, however; separates its two valves slightly, protrudes a soft organ called the ***foot***, and glides over the muddy bottom of the pond or stream, leaving a track like the mark of a finger. If our shell, figured above, were in motion, it would move from right to left. It appears, therefore, that *C* is the *anterior* end and *D* is the *posterior*. It appears that the beak is nearest the anterior end, and is turned in that direction. This valve which is figured is, therefore, the ***left valve.*** Next, let us turn our mussel around, so as to look at it hingewise. You notice

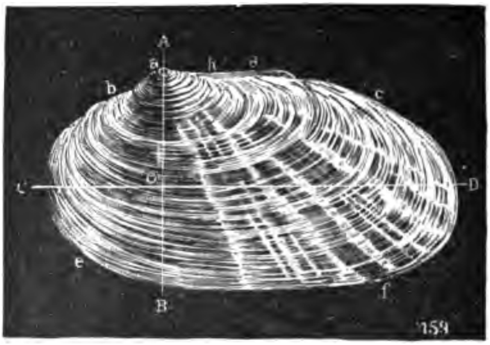


FIG. 159. —LEFT VALVE OF A COMMON RIVER MUSSEL, UNIO. *a*, Beak; *h d*. External Ligament; *b c*. Hinge Border; *C*, Anterior Border; *D*. Posterior Border; *A B*. Height; *C D*. Length; *O*. Thickness.

that the two valves are equally convex. This is what would be expected. One is a right valve and the other a left; and the law of bilateral, or two-sided symmetry, which runs through the animal kingdom, and applies, as we have seen, to animals called "radiated," requires that each shall be correspondingly developed. Let us call this *bivalvular symmetry.* Shells with this symmetry are Lamel'libranchs (*Lamella*, and *branchiæ,* gills, referring to the flat form of the gills.

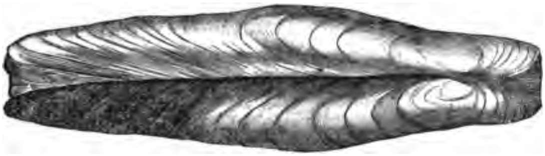


Fig. 160.—A River Mussel Viewed from the Hinge Side, Showing Equal Valves. This is an extinct species, *Anodonta angustata*, from the Catskill Sandstone, New York.

Now take one of the bivalves picked up from the Drift. There is none more common throughout the Northwest than this which is here figured, and which bears the name *Spirifera mucronata* (*spira,* a spire, *fero,* to bear, and *mucronatus,* pointed, the latter referring to its extremities). Notice that the beak is exactly in the middle of the shell between its extremities, and that the outline is symmetrical around the valve each way from the back. It must be, then, that one side of the beak is the right side, and the other the left; and if so, the two valves are *dorsal* and *ventral,* instead of right and left. Let us view a shell from the end, Fig. 162. Here we immediately perceive that the two valves are not equally convex, and have not equally developed beaks. They are not mutually symmetrical. Hence they are not right and left valves; and we conclude as before, that one is dorsal and the other ventral. The law of bilateral symmetry works, therefore, separately in each valve, and pro-

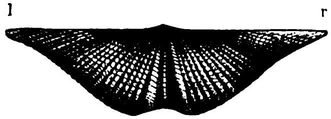


Fig. 161.—Spirifera Mucronata, Con, Viewed from the Ventral Side. Showing the Beak and Anterior Border. *r*, the Right Side; *l*, the Left.

duces what we may call *univalvular symmetry.* Shells with this symmetry are BRACHIOPODS (βραχίων, arm, and ποῦς, ποδός, foot). The valve which we will call ventral always has the most prominent beak; and it is almost always most convex or swollen. Generally, too, it has a depression or *sinus* along the middle, which corresponds to an elevation or *fold* along the middle of the dorsal valve.

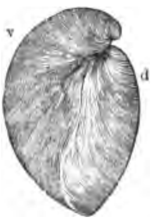


FIG. 162.—SPIRIGERA SPIRIFEROIDES. VIEWED FROM THE END, SHOWING UNEQUAL VALVES. *v*, the So Called Ventral Valve; *d*, the Dorsal.

It is not easy to determine which valve is really ventral or which dorsal. Some of the German palæontologists say the smaller valve is ventral; while the English say it is the larger. The only means of deciding is an examination of living specimens belonging to this class. But this examination is not decisive; nor does it indicate clearly which should be regarded the *anterior* part and which the *posterior*. In this state of the case, the side opposite the hinge is commonly regarded *anterior*, though the mouth was actually far back, near the beak. In this view, the right side of the shell will be on the right when the shell lies on the ventral valve, with the hinge side next the observer. This is indicated in Fig. 161, where the dorsal side is down.

These principles enable us to draw important inferences from small fragments of bivalves. Suppose the line of break of a valve is along *a b*, Fig. 163. Then, the beak and hinge line being present, it appears that the beak is central, and the valve belonged to a Brachiopod. If only a part of the hinge line is preserved, that may show symmetrical outlines each side, and thus demonstrate the same thing. If the break is along the line *c d*, and we have only the small fragment below that line, the symmetry in both directions shows that the break was opposite the middle, and the shell was a Brachiopod. If the break is along the line *e f*, and we have only the small

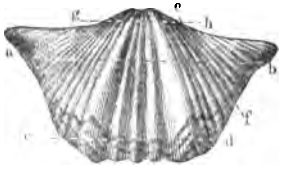


FIG. 163.—ORTHIS BIFORATA, VENTRAL SIDE.

piece on the right, if a fragment of both valves is present, their unequal convexity shows the shell a Brachiopod. If we have barely the two beaks broken off at *g h*, their unequal prominence declares a Brachiopod.

√ Now let a Lamellibranch be broken in the same various ways, and the style of the symmetry, or the lack of symmetry, will show each fragment to belong to a Lamellibranch. The student should practise much on these tests.

Let us give further attention to these Brachiopods. By collecting industriously, we find many with the two valves separated. The ventral valve is known by its sinus; and this valve, you will notice, bears a couple of small processes, or projections, *t*, *t*, Fig. 164, which are called *teeth*, one on each side of the middle, on the *hinge plate.* These are part of the hinge structure, and fit into two *sockets*, *s*, *s*, Figs. 165, 166, in the dorsal valve, which is known by the fold. This hinge structure is possessed by all Brachiopods which have a strong calcareous shell. Between the sockets of the dorsal valve is the *cardinal process.* This is a projection to which is attached the muscle which opens the two valves. In some other genera this is much more developed. It is generally

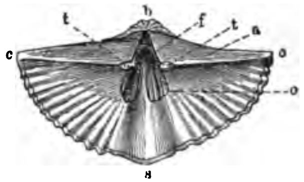


FIG. 164.—INTERIOR OF VENTRAL VALVE OF *Spirifera mucronata*, *t*,*t*. the two teeth; *b*, the beak; *c*, *c*, the cardinal extremities; *a*, the transversely striated area; *f*, the triangular fissure, showing ledge for reception of deltidium; *o*, occlusor muscular scars; *s*, the median sinus.

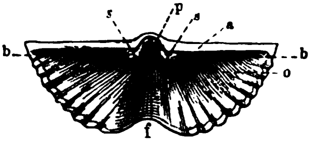


FIG. 165.—INTERIOR OF DORSAL VALVE OF *Spirifera mucronata.* *s*, *s*, the two sockets; *p*, the cardinal process (here not salient); *b*, *b*, brachial processes; *o*, occlusor muscular scars; *a*, narrow area; *f*, the median fold.

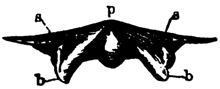


FIG. 166.—HINGE PARTS OF *Orthis subquadrata*, ENLARGED. DORSAL VALVE. *s*, *s*, sockets; *p*, cardinal process, with pinnate markings; *b*, *b*, brachial processes. (Meek.)

conspicuous in *Orthis*, as shown in Fig. 166. In the valve shown in Fig. 167, *Strophomé'na inæquiradiata*, the cardinal process is divided, and very strong. One extremity of the divaricator, or opening, muscle is attached to this process, and the other to the interior of the ventral valve. Then, contraction of the muscle, acting on the cardinal process, as on the end of a lever, lifts the dorsal valve. At the place of attachment of the divaricator muscle is a depression, or *scar*, on the interior of the ventral valve, shown at *d*, Fig. 168. There are two muscles and two divaricator scars. The valves are closed by two pairs of *occlusor* muscles, which pass directly across from valve to valve, and leave occlusor scars on the interior of each valve. These scars are shown at *o*, Figs. 167 and 168.

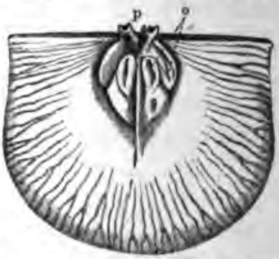


Fig. 167.—Interior of Dorsal Valve of *Strophome'na inæquiradiata*, Con. *p*, the two cardinal or divaricator processes. *o*, the impressions of the occlusor muscles. (Billings.)

The hinge mechanism is more clearly shown in Fig. 169, which represents a section through both valves of a *Strophomé'na*, from hinge to front margin. The structures are indicated in the explanation. It is evident that by the contraction of the divaricator muscle *D*, the extremity of the process *P*, must be drawn toward the point *D*, and thus the dorsal valve must turn on the hinge at *S*, as a door turns on its hinges. By this movement the valves were separated at the front margin, *M*. By the contraction of the occlusor, *O*, the valves were drawn together.

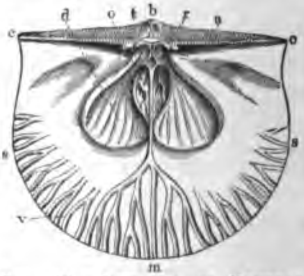


Fig. 168.—Interior of Ventral Valve of *Strophome'na inæquiradiata*, Con. *s*, *s*, the sides; *m*, the front margin; *c*, *c*, the cardinal angles; the edge of the area from *c* to *c* is the hinge line; *a*, the area: *b*, the beak, with a narrow deltidium beneath it; *d*, the divaricator impression, or muscular scar; *o*, the occlusor; *v*, the vascular impressions; *r*, the teeth.

Referring again to the ventral or toothed valve of *Spirifera mucronata*, Fig. 164, we notice, further, the flat elongate-triangular space *a*, under the beak *b*, and extending the whole length of the hinge line. This is the *area;* and most Brachiopods possess it only in the ventral valve, though some are destitute of it, and some have an area in each valve. Notice the notch or *fissure* in the margin of the area. There is a delicate ledge on the two sides, on which, in the perfect state, rests a cover, like a stove lid, called *deltidium*, in allusion to its deltoid shape. It consists of two pieces, a right and left. Sometimes the *rostral* portion (nearest the beak) of the fissure, or even the whole of it, becomes covered by an arched pseudodeltidium fixed in position. This is shown in *Cyrti'na Hamiltonensis*, Fig. 170. But here the hinge portion of the fissure is covered.

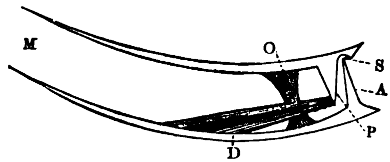


FIG. 169.—DIAGRAM OF THE HINGE MECHANISM OF A BRACHIOPOD. SECTION THROUGH BOTH VALVES FROM BEAK TO FRONT, THE UPPER VALVE THE DORSAL. *M*, the front margin; *A*, area of ventral valve; *S*, socket in dorsal valve for reception of tooth of ventral valve; *P*, divaricator, or cardinal, process (or lever); *D*, divaricator muscle; *O*, occlusor, or adductor. (After Billings.)

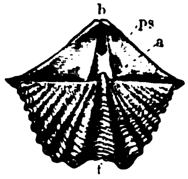


FIG. 170.—*Cyrtina Hamiltonensis.* DORSAL SIDE OF A LARGE SPECIMEN. *b*, the very prominent ventral beak; *a*, the area; *ps*, pseudodeltidium, broken away near the beak; *f*, fold of dorsal valve, on each side of which are the radial *plications*, or *ribs;* and these are crossed, especially near the margin, by concentric *lines of growth.*

Besides the muscular scars which may be seen in the interior of all Brachiopods, there are always *vascular impressions* corresponding to the positions of the vessels and structures of the internal parts. These are shown in Figs. 167 and 168. In Fig. 171 we have the interior of a ventral valve, showing various structures, and the student may exercise himself in pointing out and naming them.

Referring once more to the dorsal valve of *Spirifera mucronata*, Fig. 165, we see two projections, *b*, *b*, called *brachial processes*, the uses of which we must inquire into. In getting together a considerable number of specimens with the two valves in place, it sometimes happens that one of the valves is broken away, or weathered away, so as to reveal some internal hard structures. It is not a very extraordinary thing to find a specimen exposing an internal spire, as shov Fig. 172, th n so c as l e s ll l re be car lly pic away; student can do for himself by using a knife point, or st implement. These spires cannot be traced co y to tion with the brachial processes, but they can be se ing them. These processes, shown at *b*, Fig. 165, evi the real points of attachment of the spires to t spires are *arm supports* for fleshy, fringed *arms* which e living state, and they are, h times styled the *armature*. T are generally connected toget r by a (Fig. 173). This, in some ge ple, and nearly direct, as here sh in other genera becomes remarka fied.

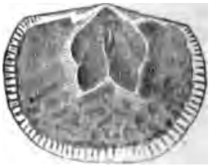


FIG. 171.—*Orthis subquadrata.* INTERIOR OF VENTRAL VALVE, SHOWING MUSCULAR IMPRESSIONS, HINGE TEETH, AND VASCULAR MARKINGS. (Meek.)

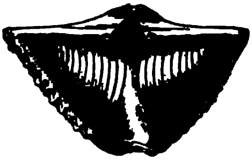


FIG. 172.—*Spirifera mucronata*, WITH DORSAL VALVE PICKED AWAY TO EXPOSE THE SPIRES. (From Nature.) The Dental Sockets and other parts may also be seen; but the spires cannot be traced completely to the Brachial Processes.

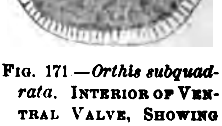


FIG. 173.—*Spirifera striata*, SOW, WITH THE VENTRAL VALVE BROKEN AWAY, SHOWING THE TWO SPIRES AND THE SIMPLE CONNECTING BAND. (Woodward.)

It is natural to wonder how the can know that a spire ex s w since there are many have no calcareous spires — some even wl ternal form the most common of those which have instance, a striking general resemblance exists between *Orthis bif'' ora' ta*, Fig. 163, and *Spirif' era mucronata*, Fig. 161. The former, on account of its form, was long called *Spirifera biforata*, until it was proved to have no spires, but on the contrary, to possess the peculiar muscular scars which characterize *Orthis*. Now, we need not wait to discover specimens naturally broken or worn so as to reveal the interior. Sometimes with a pointed tool we may pick away the shell sufficiently to reveal the existence or non-existence of a spire. In any case, we can grind down one of the valves by the means explained in Study XXX. When we reach the region of the spires, each turn will be ground off, and they will be shown on the ground surface by clear points symmetrically arranged as illustrated in Fig. 174, where the places of the cut spire turns are seen at *s*, *s*. It is evident that by continuing to grind, every structure in the shell will be successively intersected. If, therefore, we make frequent examinations as we proceed, and mark down in a succession of drawings, the positions of the sections of each structure, we shall have, in the end, the means of producing a connected delineation of the whole interior.

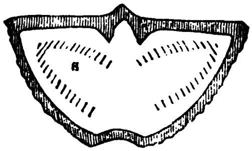


FIG. 174.—*Spirifera mucronata*, GROUND DOWN FROM BOTH SIDES. *s*, *s*, sections of the spire - whorls. (From Nature.)

The complicated armature of the little Brachiopod known as *Centronella Julia*, Fig. 187, 188, 189, was worked out by breaking in the pincers a large number of specimens, in various longitudinal and transverse positions, and marking down each time the places of the various structures broken through.

In other cases, where the substance of the shell and its filling is somewhat crystalline and translucent, we may grind off all parts of the exterior until the light shines through. Then, holding the specimen between the eye and a window, the internal structures are revealed. It was by such means that the internal spires were discovered in the little shell known as *Zygospira modesta*, Fig. 178.

EXERCISES.

Take a Lamellibranch shell and point out anterior end. The right valve. Take a Brachiopod and indicate the ventral valve. What are the external indications of the ventral valve? What the external indications of dorsal valve? Take various fragments of Brachiopods and explain what characters show them to be such. Show *areas* in specimens at hand. Show place of *deltidium*. Can you find any pseudodeltidium? Enumerate all the characters which can be seen with the valves closed. Enumerate structures concealed by the closed valves. Take a separated valve and show the *hinge plate*. Does it bear an *area?* Has it *sinus* or *fold?* Is it *dorsal* or *ventral?* If dorsal, point out the *cardinal process*. Point out the *hinge sockets*. Point out the *brachial processes*. Point out *occlusor scars* and any other characters. If it is ventral, indicate the *teeth*. Show the *divaricator scars*. To which valve are the arms attached? Construct a model, if you can, showing the mechanism of the hinge action of a Brachiopod; make the valves of wood, and for muscles use pieces of India rubber bands. Take some specimens and investigate them in the various ways described, and see what internal structures can be discovered, and report results at next study.

STUDY XXXIV.—*Further Examination of Brachiopods.*

The two spire-bearing specimens examined (Figs. 172 and 173) show the spires lying with their apices turned outward. The study of other specimens would show the spires generally in the same position. One of the commonest fossils of the northwest, however, *A'trypa reticularis*, has the apices of the spires turned toward the centre of the dorsal valve. This is well shown in Fig. 175, where we see, also, a plain connecting band lying in the hinge region, and having its middle part bent forward. This species is thin and elegant when young; but with age it grows plump and finally very obese. Different individuals also differ in smoothness and form. Consequently, inexperienced collectors, having a dozen or more of these very common Drift specimens, feel some disappointment in being told they all belong to one species. Figs. 176 and 177 are views of exteriors.

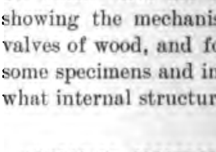
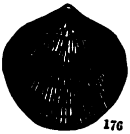


FIG. 175.—*Atrypa reticularis*, LINN. *sp.* WITH PART OF THE DORSAL VALVE BROKEN AWAY, SHOWING THE APICES OF THE SPIRES. *b*, connecting band. (After Whitfield.)

In the southern part of Ohio and Indiana is found in great abundance, an elegant little shell now known as *Zygospira modesta,* Conrad sp. (Fig. 178). Thousands of them have been picked up at Cincinnati; but they are also widely dispersed through the Northwest. Here you see very loose spires having their apices turned nearly toward the centre of the dorsal valve, as in *A'trypa.* They are also connected by a simple band; but it arises from the first turns of the spires, after they have reached the anterior part of the shell.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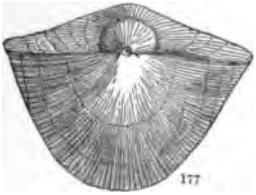
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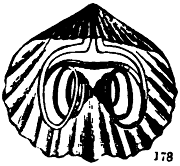
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FIGS. 176, 177.—*Atrypa reticularis*, EXTERIORS. 176, Dorsal side of thin specimen. 177, Hinge margin of an obese specimen.

FIG. 178.—*Zygospira modesta.* ENLARGED ABOUT SIX DIAMETERS. MOST OF THE VENTRAL VALVE IS BROKEN AWAY TO SHOW THE INTERNAL SPIRES.

Probably, in our collection of fossil Brachiopods, is a specimen like Figs. 179 and 162, since this species is quite common. It has a circular perforation in apex of the ventral beak. The outline is sub-oval, both valves are rather convex, and the surface is marked by concentric wrinkles or lines of growth. It is known as *Spirig'era spiriferoi'des,* and also as *Ath'yris spiriferoi'des.* It is a common thing to find one of the valves broken or worn so as to expose the internal spires. It is only a few years since Professor James Hall succeeded for the first time in showing the complicated character of the connecting band in this genus. Some conception of it may be formed from Fig. 180. Suppose we take the specimen, Fig. 179, and lay it on the dorsal side, with the beaks to the right. Then conceive both valves

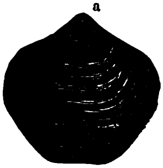


FIG. 179.—*Spirig'era spiriferoides,* Hall. VIEW FROM THE DORSAL SIDE. *a*, beak of ventral valve with circular perforation. For edge view showing commissure, see Fig. 162.

taken away and the spires left lying. Then imagine the whole of both spires removed, except their first (basal or central) turns, and their connections with the brachial plates at *a*, and also the complicated connecting band. What remains, enlarged about four times, is the part shown in Fig. 180. Consider the nearest, or left hand spire. It is indicated by the shading. It starts at *a*, from the brachial process, extends forward a short distance, then turns upward and backward as shown at *b*, and diverging somewhat toward the left margin, passes down into the dorsal valve, and begins the first or basal turn of the spire. At *i* it is represented as broken off. The connecting band springs up at *d*, as a flattened process which twists around so that the outside becomes inside and joins its fellow from the other side at *c*; then the two turn straight backward, make a right angle upward toward the ventral valve, and, separating at *f*, the left hand branch describes a backward curve to *g*, and then bends downward nearly parallel with the first turn of the spire, and forward to *h*, where it joins the spire.

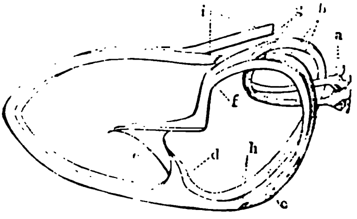


FIG. 180. CENTRAL PORTION OF ARMATURE OF *Spirigera spiriferoides*. The lower side of the figure is the dorsal side.

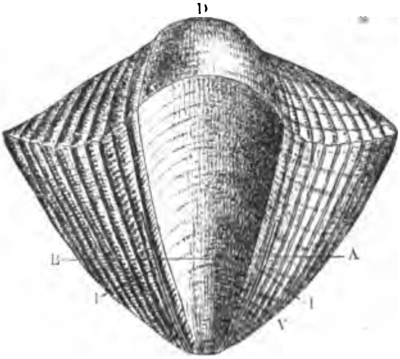


FIG. 181.—*Syringoth'yris typus*, Win. *D*, Dorsal valve. *V*, Ventral valve. *l. l*, Dental lamellæ. *A B*, line of section shown in Fig. 182. The high beak is turned down.

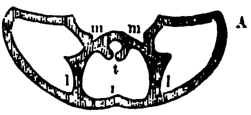


FIG. 182.—PECULIAR INTERNAL STRUCTURE OF *Syringoth'yris typus*, Win. Section along the line A B in Fig. 181. *l, l*, dental lamellæ; *m m*, transverse plate; *t*, fissured tube.

Various other modifications of the connecting band exist in other genera.

In central and northern Ohio, and in Iowa and Michigan, is another peculiar modification of the internal structure of spire-bearing shells, which has been named *Syringoth'yris.* The commonest species is *S. typus*, Winchell. It has, as Fig. 181 shows, a very high beak in the ventral valve, and an enormous triangular area, with a three-cornered opening sometimes partially closed by a pseudodeltidium, *D*, Fig. 183. From the *dental lamellæ*, *l*, *l*, Fig. 182, springs, on each side, a transverse plate, *m m*, and these meeting in the median plane curve downward and are so bent as to form the two sides of a fissured tube, *t*. Fig. 183 illustrates the modification of this structure in a European species of the same genus.

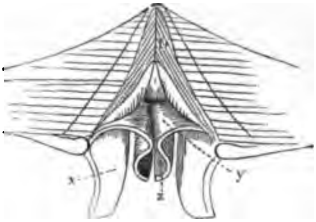
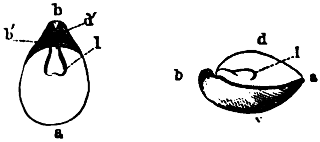


FIG. 183.—INTERNAL STRUCTURE OF *Syringoth'yris distans*, Sow. (Zittel.) From the Carboniferous Limestone of Belgium. *D*, pseudodeltidium; *x*, dental lamellæ; *y*, transverse plate; *z*, fissured tube.

All the Brachiopods thus far illustrated are spire-bearing, and constitute, with still other genera, the family *Spirifer'idæ.* How they are to be studied has been shown with sufficient detail for a student of the elements of geology. But I must not leave the impression that all Brachiopods are spire-bearing. The highest family, *Terebratu'lidæ*, is composed of genera which have a *loop*. This presents many curious modifications, but as most of the species belong to formations and ages (Mesozoic) not represented in



FIGS. 184, 185. *Terebratula Romingeri*, WIN., HAMILTON GROUP: MICHIGAN, NAT. SIZE. 184—View from dorsal side, with most of dorsal valve removed, showing short loop, *l*; *b'*, beak of dorsal valve; *d'*, deltidium.

185—VIEW FROM LATERAL COMMISSURE, SHOWING THE LOOP FROM THE SIDE. *a*, anterior margin; *b*, beak of ventral valve with circular perforation; *d*, dorsal valve; *v*, ventral valve; *l*, loop.

the rocks occurring near the homes of most who use this book, I shall offer only two illustrations. The first is *Terebrat'ula.* The form of the shell is ovoid — very different from most of the spire bearers; the hinge line is short, Fig. 184, and the ventral beak has a circular perforation. The exterior is nearly smooth and marked by a few concentric striations, or it is radially striated and rarely plicated. Examined with a lens, it is seen marked by thousands of minute *punctations,* like needle pricks, and this is true of the whole family. The armature consists of a *loop,* which extends from the brachial processes forward, and is generally turned back into the ventral valve at the anterior extremity. This is shown in Figs. 184, 185, and more in detail in Fig. 186.

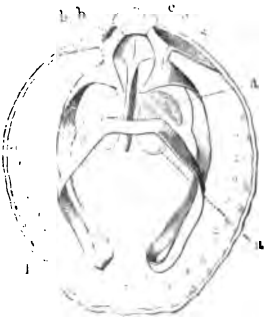
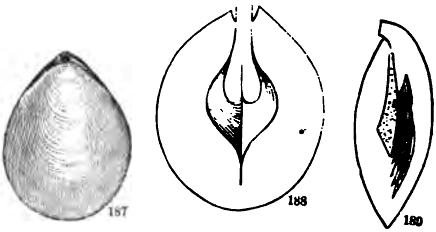


FIG. 186—LOOP OF *Terebrat'ula (Waldheimi'a) flavescens.* Recent. [The name of a *sub-genus* stands in parenthesis after the name of the genus.] *c c,* cardinal process; *s,* dental sockets, connected by hinge-plate; *l,* loop, the anterior portion of which is seen reflected; *a, a,* anterior and posterior adductor or occlusor scars (each in pair), with the median septum between. This sub-genus of *Terebratula* has a large and reflected loop. Compare Figs. 184, 185.



FIGS. 187, 188, 189 — *Centronella Julia,* WAVERLY OR MARSHALL GROUP. 187. View from dorsal side, ×3. 188. Dorsal view of loop, ×4. 189. Lateral view of loop and vertical plate, ×4.

The only other genus to which I shall refer is *Centronella.* The loop has been fully worked out in the species *Centronella Julia,* which is illustrated in Figs. 187, 188, 189. The loop is shown in Figs. 188, 189. The geological position is possibly in the Chemung.

Many of the Brachiopods found in the Drift are entirely destitute of calcareous armature, either spire or loop. An extremely common form is somewhat semicircular in outline, having the ventral valve very convex and the dorsal concave. Some of these forms were figured for the purpose of showing hinge structures and other internal characters. (See Figs. 167, 168, 169.) Here, in Fig. 190, is given a view of the ventral valve of *Strophome'na inæquiradiata*, Con. Fig. 191 shows the dorsal valve of *Strophome'na alternata*, Con., as also the area and depressed beak of the ventral valve, and the arched pseudodeltidium. The dorsal valve of *Strophomena* is externally concave, as is shown by the longitudinal section, Fig. 192.

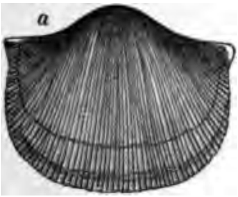


Fig. 190—***Strophome'na inæquiradiata***, DEVONIAN. **View from** ventral side. **(Billings.)**

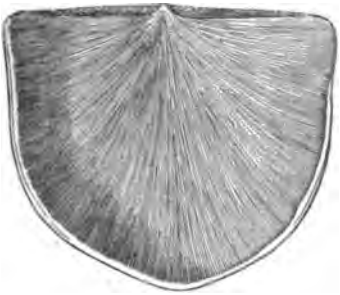


Fig. 191—*Strophome'na alternata*, CAMBRIAN. Dorsal view, showing also area and pseudodeltidium of ventral valve. (Meek.)

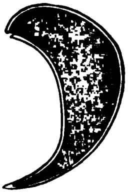


Fig. 192—LONGITUDINAL SECTION THROUGH THE TWO VALVES OF *S. inæquiradiata*. (Billings.)

The further study of Brachiopods belongs in an advanced course. The descriptions and illustrations of internal structures already given are far more than is customary in elementary treatises; but they have been given because the illustrative specimens can nearly all be picked up from the Drift, and worked out by the student. They belong to the accessible inductive data of the science; and because the student can reach them by his own manipulation and research, I am sure they will awaken an eager interest.

The student making actual researches will be aided by the following table, in which the characters pertaining to each valve are brought together by themselves:

VENTRAL VALVE.	DORSAL VALVE.
EXTERNAL CHARACTERS.	EXTERNAL CHARACTERS.
Most prominent Beak.	
Perforation for pedicle, if any.	
Most conspicuous Area.	Area generally wanting.
Notch or Fissure in Area.	Notch present when area is.
Deltidium or False Deltidium.	
Sinus, if one exists (save in very few forms).	Fold, if one exists (sinus in very few forms).
INTERNAL CHARACTERS.	INTERNAL CHARACTERS.
Teeth for articulation.	Sockets, to receive teeth of opposite valve.
Divaricator Scars (generally one large one each side of median line).	Cardinal Process (for attachment of Divaricator muscles).
Occlusor Scars (generally two crowded between the rear parts of the Divaricators).	Occlusor Scars (generally four).
Dental Lamellæ.	Foveal Plates bearing the Sockets.
	Armature (Spires or Loop).
	Crura (or basal portions of Armature).
	Brachial Process (for attachment of Armature).

Finally, to aid the real working student, I append an analytical table, but *only* of the genera here illustrated, most of which are by far the commonest, whether in the Drift or in the rocks. Two or three genera are here included, because they possess interesting internal characters. The table is based on the method which the young student will naturally pursue — first, observation of external form and other characters; then, study of internal characters:

TABLE FOR DETERMINATION OF SOME COMMON BRACHIOPODS.

Hinge line long and straight; often the greatest transverse diameter of the shell. Form of shell somewhat triangular or semicircular. Beak imperforate. Surface plicated or striated.

  Sinus and fold well developed. Form more or less angulated at the hinge extremities; sometimes rounded. Exterior distinctly, often strongly, plicated.

    Area only in ventral valve, which has a triangular notch. Armature consisting of two spires having the apices turned to the right and left.

No pseudodeltidium.

SPIRIFERA. Figs. 161, 162, 164, 165, 172, 173, 174.

Pseudodeltidium present. Ventral beak very prominent; area very large.

Exterior sharply plicated. Pseudodeltidium complete. Shell structure punctate.

CYRTINA. Fig. 170.

Exterior with medium-sized, rounded plications. Pseudodeltidium partial. Notch with a deep transverse plate, beneath which is a fissured tube.

SYRINGOTHYRIS. Figs. 181, 182, 183.

Area in each valve, nearly equal in the two. Triangular notch in each valve. No calcareous armature. Saucer-like pits within for insertion of muscles; exterior sharply plicated.

Delthyroid Section of ORTHIS. Figs. 163, 166.

Sinus and fold wanting or feebly developed. Outline somewhat semicircular. Area in each valve, the ventral the broadest, and having a triangular notch, which is sometimes covered by a pseudodeltidium. Ventral valve very convex; the dorsal often concave externally. Surface radiately striated. Cardinal process bifid and prominent. Calcareous armature wanting.

Non-resupinate Section of STROPHOMENA. Figs. 167, 168, 172, 191, 192. [The "resupinate" section has the ventral valve concave, and dorsal convex.]

Hinge line short, generally inconspicuous. Exterior plicated, concentrically wrinkled, or smooth. Perforation at or beneath the ventral beak, either conspicuous or half-concealed. Sinus and fold wanting or indistinct. Form ovoid.

Area beneath ventral beak, and having a triangular notch. Spires within.

Rostral perforation conspicuous. Exterior concentrically wrinkled. Sinus and fold nearly absent. Apices of spires turned outward.

SPIRIGERA. Figs. 179, 180.

Rostral perforation concealed or inconspicuous. Apices of spires turned toward centre of dorsal valve.

Exterior with strong, sometimes squamous or even spiny, concentric markings, and strong radial plications. Adult shell tumid. Coils of spires numerous and crowded.

ATRYPA. Figs. 175, 176, 177.

Exterior without conspicuous concentric markings; radial plications small. Adult shell small and lean. Whorls of spires few and loose.

ZYGOSPIRA. Fig. 178.

Area beneath ventral beak wanting or scarcely perceptible. Notch usually opening into the large, circular rostral perforation, and generally closed by a pair of deltidial pieces. Exterior smooth or concentrically lined, or radially striate or plicate. Sinus and fold sometimes wanting, generally little developed, and sometimes both valves feebly sinuate near anterior margin. Shell minutely punctate. Armature a loop.

The loop anteriorly folded back; not embracing a free, vertical plate.

TEREBRATULA. Figs. 184, 185, 186.

The loop not folded back anteriorly, embracing a vertical, free, longitudinal, spiny-margined plate.

CENTRONELLA. Figs. 187, 188, 189.

EXERCISES.

What results have you reached in the investigations proposed at the last study? Test the "Table for Determinations" with all the Brachiopods you get. Try to make a model of the armature of *Spirigera*, using cork, pasteboard, and mucilage. Make a model of the armature of *Centronella*. Make a model of the armature of *Terebratula flavescens*. Make a model of the hinge region of *Syringothyris*, using white pine, pasteboard, and mucilage. Copy, with lead pencil or with India ink, any of the illustrations of Brachiopods. Make a drawing of a Brachiopod collected by yourself. Grind down a specimen so as to demonstrate the nature of its armature. Show a specimen having a pseudodeltidium. Pick out all the specimens differing from any of the genera here described. Take one of these and write out a description for yourself, first using the external characters. Make a drawing of the same. Find out all possible of the internal characters. Write a description of them. Which of the genera here described does this specimen most resemble? What prevents its belonging to that genus? Take another specimen different from any genus here described, and state whether you think it has any calcareous armature. If it has, do you think it a pair of spires? Have you ever noticed a resupinate species? What genera have an area in each valve?

We have now pursued this method of instruction as far as the time of the elementary student will permit. We have shown him how to take his lesson from nature, and have inspired, it is hoped, some enthusiasm for the science. He has collected; he has observed; he has drawn inferences; and from these he has reasoned out other facts which could not be observed. This is the method by which investigators have created the science. It is the natural method of beginning the study. The method might very advantageously be extended over various departments of the field not yet mentioned; but our time is insufficient.

The facts and conclusions reached thus far must necessarily exist for the present in a partially undigested, confused, and unsatisfactory state. The scattered facts and principles reached by the observational and inductive method which we have pursued ought now to be reviewed under some systematic and logical arrangement. A good amount has already been done in the course of these Studies, to bring facts into systematic arrangement; but it would be well if the student could now review the whole body of facts in logical order. As this, with most students, would require more time than can be afforded, we are forced to reduce Part II chiefly to a statement of some broader generalizations than have yet been made, and the presentation of some important additional facts and principles which cannot be omitted from the elements of the science.

PART II.

SYSTEMATIC STUDIES;

OR, OUTLINES OF A LOGICAL ARRANGEMENT OF THE FACTS AND THE LESSONS THEY TEACH.

General Definitions and Divisions of the Subject.

GEOLOGY, as a term, is derived from γῆ, the earth, and λόγος, a discourse.

As a science, it treats of the earth's Constitution, Condition, History, and Adaptations to human wants.

The following scheme shows the logical subdivisions of the science:

- Constitution,
  - Material (I. Lithological).
  - Mechanical (II. Structural).
- Condition,
  - Temperatures,
  - Solidity or Fluidity,
  - Rigidity.
- History, and its Evidences,
  - Grounds of Inference,
    - Existing Dynamic Agencies.
    - Records of Former Actions,
      - Thermal,
      - Chemical,
      - Mechanical,

(III. Dynamical.)

      - Organic.
        - (IV. Palæontological).
        - (V. Formational).
  - Succession of Events (VI. Historical).
- Adaptations (VII. Economical).

The terms above appended in parentheses are the general divisions of the subject which will be employed in the following synoptical treatment. They may be defined as follows:

I. LITHOLOGICAL GEOLOGY. That division of Geology which treats of the elementary and mineralogical constitution of the Rocks, and their mechanical condition.

II. STRUCTURAL GEOLOGY. That division of Geology which treats of the Superposition, Succession, Attitudes, Accidents, and Classification of Rocks, both Stratified and Unstratified.

III. DYNAMICAL GEOLOGY. That division of Geology which treats of the Forces and Modes of Action which have produced the results witnessed.

IV. PALÆONTOLOGY. That division of Geology which treats of the Organic Beings, vegetable and animal, which lived in former ages of the world.

V. FORMATIONAL GEOLOGY. That division of Geology which treats of the successive systems of rocks and their subdivisions, and indicates the order of distribution of fossil remains through them. (Divisions IV and V furnish the principal data of Division VI.)

VI. HISTORICAL GEOLOGY. That division of Geology which narrates the succession of terrestrial events, as induced from the data supplied by the preceding divisions, and as deduced from the recognized principles of the science.

VII. ECONOMIC GEOLOGY. That division of Geology which enumerates, describes, and locates the various mineral substances possessing utility for man, and explains the methods of extracting them from the earth, and reducing them to an available condition.

In the following sketch, none of the above divisions can be carried beyond a very elementary treatment, and two of them must be dismissed with references to Studies in Part I.

That part of the earth which is accessible to our investigations is called the *crust*. Nearly the whole of the earth's crust is in a *mineral condition.* A *mineral* is a definite chemical compound, not depending on the presence of life for its maintenance. A *rock* is any mass of mineral matter. Most of the matter of the rocks has been arranged through the action of inorganic forces; but some portions of it are of *organic origin;* though nothing which can be said to form a part of the earth is properly *organic.* A rock is not necessarily solid.

CHAPTER I.

LITHOLOGICAL GEOLOGY (PETROGRAPHY);

OR, WHAT HAS BEEN LEARNED ABOUT THE MATERIALS OF THE EARTH.

[The attention already paid to the subject in Part I renders it unnecessary to introduce a complete summary in this place, the more so since summaries and tables covering most of the topics may there be found.]

§ 1. Chemistry.

Some rudimentary ideas may be found in Study IV.

§ 2. Mineralogy.

See this subject explained in Studies V, VI. See the General Review, the Table of Composition of Minerals, and the Table for Determinations, in Study VII.

§ 3. Kinds of Rocks.

A *rock* is a mass of mineral matter, consisting of a single mineral, or an aggregate of minerals. Rocks are characterized and distinguished by their mineral constitution, their physical structure, and their position or attitude in reference to other rocks.

1. PHYSICAL CONDITIONS OF ROCKS.

(1) **Mineral Constitution.** (*a*) ESSENTIAL CONSTITUENTS. Those minerals whose presence determines the specific identity of the rock, and the absence of one of which would make it some other rock species. The particular specifications belong to the definitions of the rock-species which will be cited beyond.

(*b*) ACCESSORY CONSTITUENTS. Those minerals which are present in addition to the essential ones. If abundant enough to impart any conspicuous or otherwise important character, they furnish a qualifying term for the name of the rock, as shown below :

Quartzose, or *quartziferous*, containing quartz. The qualifying constituent may be of such variety as to render a rock *amethystine*, *agatiferous*, *chalcedonic*, *flinty*, *cherty*, or *jaspery*. When the quartz is in small grains, the rock is *arenaceous*. When it is intimately disseminated, or combined, the rock is *silicious* — a term often used, also, as equivalent to quartzose.

Ferruginous, when stained red or yellow by the presence of oxide of iron. If distinct grains of hæmatite or limonite are present, the rock is *hœmatitic*, or *limonitic*.

Pyritous, or *Pyritiferous*, containing pyrites.

Saliferous, containing halite, either crystalline, or in solution.

Feldspathic, or *Felsitic*, containing feldspar; but the latter term may be restricted to the presence of feldspar in the state of a matrix, or ground holding other minerals imbedded or intimately mixed; but in this sense felsitic is only the adjective form of felsite.

Kaolinic, containing kaolin. *Micaceous*, having disseminated scales of mica. *Hydromicaceous*, having disseminated hydromica. *Talcose*, or *Talcitic*, having talc in scales or grains. *Serpentinous*, containing serpentine. *Chloritic*, containing chlorite.

Amphibolic, containing amphibole. Varieties of this are *hornblendic*, *tremolitic*, and *actinolitic*.

Pyroxenic, containing pyroxene. Varieties are *augitic* and *diallagic*.

Tourmalinic, containing tourmaline. *Epidotic*, containing epidote. *Garnetiferous*, containing garnets.

Calcitic, or *calciferous*, containing calcite. But when calcite is present in an impure or amorphous condition, the rock is commonly described as *calcareous*. This term is also used when calcite is the essential ingredient.

Dolomitic, containing dolomite. *Sideritic*, containing siderite.

Argillaceous, having some clayey matter disseminated. But when mingled in undiscernible particles, or in a state of intimate union, the term *aluminous* is preferable.

Carbonaceous, with carbon disseminated, generally imparting a dark or black color. *Bituminous*, containing bitumen. *Petroliferous*, containing petroleum.

Many of the same terms are employed to express the essential constituents of rocks. Thus a *micaceous* rock is one, also, which has mica for an essential constituent. A *talcose* schist is one characterized by talc. Ordinarily, where practicable, the essential constituent is indicated by retaining the substantive form in a compound word. Thus mica-schist, hornblende-schist, having mica or hornblende as essential constituent; while micaceous sandstone, micaceous hornblende-schist, hornblendic mica-schist, and hornblendic gneiss, indicate mica and hornblende as mere accessories. It would, perhaps, be a convenience if the termination *-ose* (*osus*, abounding in) were employed to denote an essential constituent, in distinction from an accessory one. We should then have rocks characterized as *micose, calcarose, serpentinose, augitose, carbonose*, etc., in distinction from others simply *micaceous, calcareous, serpentinous, augitic, carbonaceous.*

(2) **Physical Constitution.** (*a*) FRAGMENTAL ROCKS are such as are composed of fragments of other rocks. Of these, a

Conglomerate is composed of coarse rounded fragments and pebbles; and when of the size of mustard seed, with some smaller, it is a *grit*. A cemented mass of angular fragments is a *breccia.*

Sandstone, composed of fine rounded grains — generally grains of quartz — more or less firmly cemented.

Granular signifies composed of grains. Granite is a granular rock; but most granular rocks are not granite.

Earthy, lustreless, of indistinguishable particles and not hard-indurated.

Sand. Fine grains of any sort of mineral or rock, most frequently silicious. When of volcanic origin, it is *Volcanic sand* or *Peperino*, derived from the "cinders" or "ashes" (comminuted lava) produced during an eruption. When the ashes become consolidated they constitute volcanic *tufa.* None of these substances have *any fixed constitution.*

(*b*) CRYSTALLINE ROCKS. Consisting chiefly of distinct crystals or fragments of crystals. Careful observations show that this condition sometimes results from *solution in water*, as in depositions from springs; sometimes from *solidifying from fusion*, as in lavas and other erupted rocks; and sometimes through *metamorphism* of deposits originally fragmental, as in the common crystalline rocks.

Phanerocrystalline, having the separate crystal fragments visible to the naked eye, or with a simple lens.

Microcrystalline, exceedingly fine-grained, requiring a compound microscope and thin slices to distinguish the constituents (Rosenbusch).

Cryptocrystalline, when no magnifying power employed on thin sections discloses the constituent minerals; while at the same time, the whole mass, being composed of doubly refracting particles, has evidently a crystalline texture (Rosenbusch).

Microfelsitic, partly crystalline, but with an optically isotropic or uncrystalline base, used especially for felsites.

Colloid (like glue), glassy and homogeneous under high powers. When a rock of colloid texture reveals lines suggesting a flow of molten matter, these are styled *fluidal*, and the texture is *fluidal*.

Porphyritic, having distinct crystals disseminated through a mass of some other kind, either phanerocrystalline or cryptocrystalline. If the disseminated crystals are of feldspar, we say simply, the rock is porphyritic; and if the base is also felsitic, the rock is *porphyry*. But if the disseminated crystals are pyroxene or hornblende, we say the rock is *porphyritic with pyroxene* or *with hornblende.*

(*c*) RELATIONS OF ROCKS TO MECHANICAL AND CHEMICAL ACTIONS. *Hardness* depends on the adhesion of the particles under pressure. Quartz is hard, but gypsum is soft.

Brittleness is determined by the readiness of the particles to separate under a sudden shock, like a blow with a hammer. Quartz is brittle though hard.

Toughness is reluctance of particles to separate under a sudden shock or blow. Hornblende, pyroxene and serpentine are tough, though more or less soft.

Compactness is closeness of texture; but it does not necessarily make a hard or tough rock. Serpentine is compact though soft, and a granular quartzite is hard, though not always compact. *Porosity* is the reverse of compactness.

Friability is incoherence of parts. The parts, however, may possess any degree of hardness, as in friable sandstones.

Durability is absence of disposition to change under the influences exerted. Against durability is *solubility* of the rock (like limestone or gypsum), or of the cementing material of its parts, as the calcite in some sandstones; also *porousness*, which admits water to augment its solvent action, and permits, also, the entrance of frost to exert its mechanical action.

(3) **Stratified and Unstratified States.** (*a*) *The Stratified Condition.* The materials are arranged in layers or beds called *strata*. These may exist in any imaginable attitude or condition. Strata are separated by narrow openings. These constitute *seams* when filled with some special sort of matter (Fig. 193). When, however, a very thin layer between two strata is a result of sedimentation it is a stratum or bed.

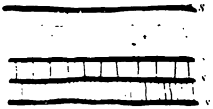


FIG. 193.—SEAMS AND STRATA. THICK-BEDDED AND THIN BEDDED, WITH SEAMS s, s, s, between them.

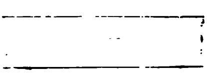


FIG. 194. LAMINATED STRATIFICATION OR SHALY STRUCTURE.

Massive, or *Thick-bedded*, indicates thick or heavy strata. The term has no definite limits, but we may say the strata are a foot or more in thickness.

Thin-bedded refers to thin strata, but has no precise meaning. We may say the strata are four inches or less in thickness.

Shaly, having the materials deposited in very thin layers or leaves as in Fig. 194.

Laminæ are thin subdivisions of strata. The layers of a shale are laminæ.

(*b*) *The Unstratified Condition.* This exists when the evidences of stratification are wanting. The metamorphic rocks, for the greater part, show but feeble and remote signs of stratification; but they may generally be discovered in (*aa*) the *seams* which intersect the rock-mass, or (*bb*), *lines* or *bands* in the distribution of the mineral constituents, especially mica, hornblende and pyroxene, or (*cc*) in some other inequality in the distribution of the constituents — as in color or coarseness, or finally (*dd*) in the fact that the scales and lamellæ of the minerals are mostly disposed in one direction. (This disposition of scales, however, is not necessarily the result of sedimentation.)

2. METHODS OF STUDYING ROCKS.

(1) **Physical Examinations.** Study of the mineral constituents through their physical characters; study of the physical constitution and condition of the rocks; whether stratified or unstratified (massive); whether crystalline, uncrystalline, colloid, or porphyritic; and if stratified, whether thick or thin bedded. Here are embraced also, observations of color, lustre and weight. This is the method most available for the elementary student, and hence, the one here employed.

(2) **Microscopic Examinations.** Thin, transparent or translucent slices of rocks prepared as indicated on page 205, and examined with a polariscope-microscope, reveal, by the optical and minute textural characters shown, the nature of the constituent minerals. This is accomplished either in phanerocrystalline or microcrystalline rocks. This method of study, introduced within a few years, is constantly growing in importance, and has become indispensable in all thorough work. But we must be content to postpone the employment of it to an advanced course.

(3) **Chemical Examinations.** At one period in the history of petrology the chemical investigation of rocks was considered, perhaps justly, as the most exact method available; and classifications were then based on chemical constitution. Various expedients for arriving, through chemical processes, at the mineral ingredients of rocks, have been proposed; but we need not explain them here. Aggregate or average chemical characters are still employed, as in the terms *acidic* and *basic*, but on the whole, chemical methods with rocks generally have fallen into

disuse. It may be necessary to add, however, that in the study of minerals, chemistry holds the first place.

(4) **Magnetic Examinations.** These have some repute in the study of certain classes of rocks, and magnetic indications are probably useful in explorations for beds of iron ore (see T. B. Brooks in *Mich. Geol. Rep.*, 1869–73, Vol. I, Chap. viii). But it is not appropriate to enter upon the subject in this place.

3. MOST IMPORTANT SPECIES OF ROCKS.

We again refer the reader to Part I. The principal species and groups of rocks are treated in Studies IX–XIII. In Study XIV we have also a retrospect, embracing a systematic Table of Rock Structure, a Table of Rock Compositions, and also a Table for Rock Determination. The latter indicates the eleven series under which the rocks may be classed.

CHAPTER II.

STRUCTURAL GEOLOGY (GEOGNOSY);

OR, WHAT HAS BEEN LEARNED ABOUT FORMATIONS.

§ 1. General Definitions.

FORMATION. The term *Formation* is used in Geology, as elsewhere, to express the abstract conception of *process or act of forming.* It is also used in a concrete and specially lithological sense to denote *that which has been formed.* It is the lithological result of an action or concert of actions producing something possessing unity and completeness. A particular "formation," though it may be a constituent of something which embraces it, has limits and completeness in itself. A bed of shale is a formation, and so is a bed of sandstone; and these two may be so affiliated together, and so differentiated from other beds of rocks, as to constitute a formation. A doleritic dike is also a formation; and if it intersects the shale and sandstone, the three constitute a formation. The term is thus general or common, without fixed breadth of application. The term *terrane* is employed in a sense almost identical.

The most frequent application of the term formation is to stratified beds, and hence ordinarily it refers to beds belonging to one particular interval of time, as the "Cretaceous formation," the "Potsdam formation."

Sedimentation. The deposition of rock material by subsidence in water.

Stratification. The arrangement of rock material in successive layers. This generally results from sedimentation.

Layer. A single sheet of sedimentary material.

Stratum. A series of layers intimately connected. The layers may differ in color or fineness, or, within small limits, in material. The term *bed* is often employed in the same sense. A bedded rock is a stratified rock.

Seam. The parting plane between two strata. It is generally in the nature of a thin, non-sedimentary layer, different from the contiguous layers above and below. The substance of seams is often clay, less or more bituminous, or even pure inspissated bitumen or coaly matter.

Fossil. The relic or trace of an organic being, animal, or plant, embraced in the substance or open spaces of a rock or a formation. Rocks containing fossils are *fossiliferous.*

§ 2. Accidents of Stratified Rocks.

1. **Accidents of Sedimentation.** The terms *conglomerate*, *arenaceous*, *granular*, *sandy*, *shaly*, and *earthy* are briefly defined (p. 250) in explaining terms employed in rock descriptions. It is only necessary to add the following:

Oblique Lamination. This is seen when the s of nation are inclined to the plane of stratification. The clination of the laminæ may persist throughout a c e: of tum (Fig. : or frequ i v b of of within one stratum, lar, and others horizo laminated (Fig. 196).

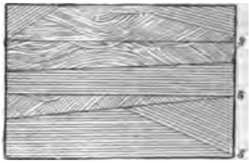


FIG. 195.—OBLIQUE OR CROSS LAMINATION IN POTSDAM SANDSTONE, WIS. (After Strong.) The horizontal *strata* are separated by the seams *s*, *s*, *s*. The lamination in each stratum (except part of the lower) is unconformable—oblique and irregular.

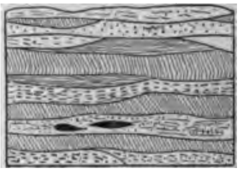


FIG. 196.—EBB AND FLOW STRUCTURE. (Foster and Whitney.)

Drift Structures. Tl d terminations of laminat regular changes in inclination of laminæ, as shown

Besides its occurrence in regularly stratified formations, it is everywhere shown in the "Modified Drift" (see Figs. 7, 8, and 9).

Ripple Marks. Ridges like miniature waves on the surface of a stratum. They are often seen on the surface of sand drifted by the wind.

Rain Prints. Marks of rain drops, produced when the stratum was a soft beach sediment.

Mud Flow. Appearances like flowing mud on the surfaces of strata. (Compare Fig. 199).

2. **Accidents of Secondary Origin.** Many changes have taken place in the structure and mechanical condition of strata since the time of their original deposition.

Mud Cracks. Irregularly intersecting fissures, appearing like cracks produced in drying, and subsequently filled by other sediments. The filling of each crack shows a median joint or fissure, as if the deposit had flowed down each of the opposing walls, forming layers which met in the middle.

Cone in Cone. A singular and unexplained structure seen in some argillaceous strata, having lines of structure arranged in conical or trumpet-shaped forms in several series, which seem to be associated together in nests.

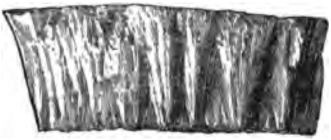


FIG. 197.—CONE IN CONE STRUCTURE.

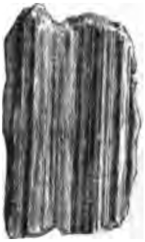


FIG. 198. TOOTHED STRUCTURE, OFTEN CALLED *Lignilites.*

Lignilites, Stylolites, or Toothed Structure. Partings in certain limestones which are roughly conformable with the stratification, but have their surfaces studded with tooth-like projections, which interlock from opposite sides, and appear as the terminations of striated or furrowed pegs which penetrate the rock vertically, above and below, and at a distance generally less than three inches become confluent with it. The partings and the peg-like forms are generally blackened with bituminous matter.

Concretionary Structure. This consists of concentric layers of materials around some centre, at which may be found frequently a crystal or some organic fragment. Instead of concentric layers, the structure is often radiated. Sometimes these masses show shrinkage cracks, which have been subsequently filled, and thus form what are vulgarly called "turtle stones," and sometimes "septaria." Kidney iron stone consists of concretions (see p. 47). Some alumino-calcareous concretions assume very curious forms, four of which are shown in Fig. 199. Many are handsomely spherical or spheroidal. Others present a striking resemblance to flowing mud. The concretionary structure can often be traced in strata where no sepa-

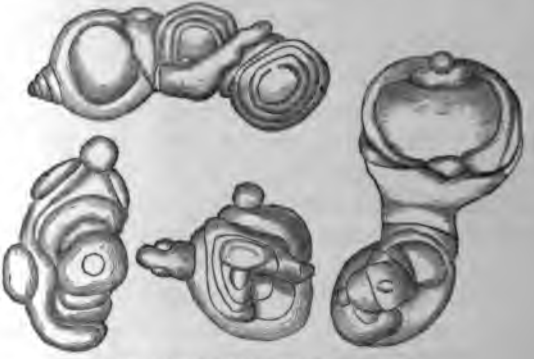


FIG. 199.—CALCAREOUS CONCRETIONS.
(From the Portage Shales of northeastern Ohio.)

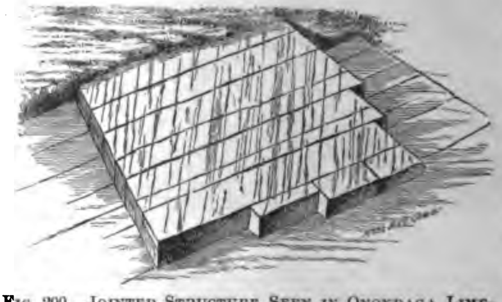


FIG. 200.—JOINTED STRUCTURE SEEN IN ONONDAGA LIMESTONE AT "SPLIT ROCK," NEAR SYRACUSE, N. Y. (Vanuxem.)

rable concretion has been formed. The lines pass across the bedding planes and inclose spaces which partake of the general stratification, thus showing that the structure was a secondary result (p. 48).

Where small spherulitic concretions are plentifully disseminated through limestones, the latter become *pisolitic* (*pisum*, a pea), or oölitic (*ὠόν*, an egg).

Jointed Structure. The presence of one or more sets of divisional planes or cracks which pass across the stratification, extending to great depths, and divide the rock mass into cuboidal segments. These planes sometimes extend in rigidly fixed directions for many miles, and those in each set are strictly parallel.

Slaty Structure, or *Slaty Cleavage*, consists in a system of closely crowded joints which create a tendency in the rock to split in thin sheets, as in roofing slate. This cleavage generally crosses the planes of bedding, but sometimes corresponds with them.

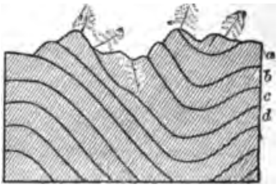


Fig. 201.—Slaty Structure, as Seen in Slates in Columbia Co., N. Y. (Mather.)

The strata *a*, *b*, *c*, *d*, etc., are crossed by crowded cleavage planes parallel with each other, but wholly independent of the stratification.

Polished Faces, "Slickensides." Polished surfaces along the faces of a fissure intersecting the stratification, caused apparently by friction of opposed surfaces resulting from slight movements in the earth's crust.

Sand Blast Action. The polishing of rock surfaces, especially of pebbles and bowlders, by the friction of dry sand driven by the wind.

Metamorphism. A change in the condition of a sedimentary rock by which the lines of sedimentation are obscured or obliterated, the fossils destroyed, and a crystalline condition superinduced. The work of metamorphism has been accompanied by a softening or aqueous semi-fusion of the materials, the formation of new crystalline combinations, the moulding of certain crystals around others (as quartz around feldspar), and sometimes the squeezing of the softened rock into fissures, imparting to it the vein-like condition of a true erupted formation. (See further particulars in Chapter III, § 3, (4).)

3. **Attitudes of Strata.** It is probable that most strata were originally horizontal, or nearly so. Observations upon modern sedimentation show that sediments falling upon an uneven bottom tend to the lower levels until the inequalities disappear. After that, the successive sedimentary sheets are parallel and practically horizontal.

The actual attitudes of rocky strata, however, are generally at a wide divergence from undisturbed horizontality. In many instances a whole formation, over hundreds of square miles, presents a regular or gently undulating inclination. In other cases, in addition to the general inclination, the subordinate beds and layers have undergone a complicated disturbance.

Outcrop is the appearance of a stratum or formation at the surface. Generally the outcrop is the weathered termination or edge presentation of strata which from that point disappear beneath other formations.

Dip is the direction in which a stratum descends below the horizontal plane. The *amount of the dip* is the angle made with the horizon.

Strike, *Trend*, or *Axis* is the direction in which the outcrop continues along the surface. If the surface were level, the strike would always be at right angles with the direction of the dip. So, also, if the slope of the surface were in the direction of the dip or the opposite direction.

Breadth of Outcrop. This is the distance, measured along the surface of the earth, between the upper and under sides of the formation. Its amount depends, in a level region, on the thickness of the formation and the steepness of the dip. More generally it depends on the thickness of the formation and the angle of *plunge* beneath the surface. This is equal to dip plus the angle of inclination of the surface if it rises in the direction of the dip, and minus this angle if the surface descends in the direction of the dip. The relation is such that

$$\text{Breadth of Outcrop} = \frac{\text{Thickness of Formation}}{\text{Sine of Plunge.}}$$

Hence, when the plunge is 90°,

$$\text{Breadth of Outcrop} = \text{Thickness of Formation.}$$

Hence, also,

Thickness of Formation = Breadth of Outcrop × Sine of Plunge.

Synclinal Axis. This is a line toward which the strata dip from opposite sides. (See Fig. 50.) A general descent of the strata from opposite sides, across a broad region, regardless of subordinate flexures, is a *Geosynclinal* arrangement.

Anticlinal Axis. The line from which the strata dip in opposite directions (Fig. 45). A *Geanticlinal* expresses a general anticlinal tendency of strata over a wide extent, independently of subordinate undulations of the surface.

Quaquaversal Dip. A dip in all directions from a common point.

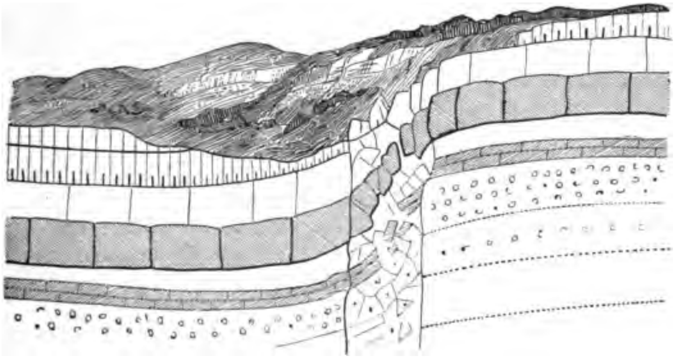


FIG. 202.—A FLEXURE BECOMING A FAULT. (Powell.)

The disturbances to which the earth's crust has been subjected have not only tilted the strata, but subjected them to extensive fracture. A line of fracture generally pursues a direct course for several miles—sometimes even a hundred miles or more.

A *Fault* or *Dislocation* is a displacement of strata along a fracture, which destroys the correspondence of the strata on opposite sides. They are common in mountainous regions. Faults may attain to displacements of many thousand feet. A fault results from an *upthrow* on one side or a *downthrow* on the other. Faults are illustrated in Figs. 86, 34.

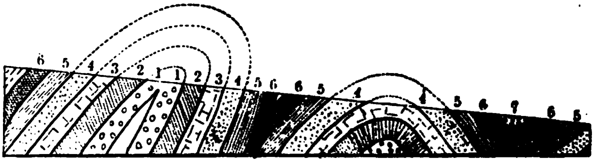


FIG. 203.—INVERTED SUPERPOSITION.

A *Flexure* is a bending of the strata. When the flexure is abrupt, or considerable in vertical extent, it often results in fracture and faulting. In many instances a fault may be traced into a shattered flexure, and thence to an unbroken flexure, which still beyond dies out.

A *Fold* is a series of strata uplifted to a more or less elevated anticlinal axis. Generally, the steepness of the dip is greater on one side of the fold than on the other. In other words, fold is p over. Som mes the inclin on be- comes s give the on one side a tical positi (Fi l,), or e vert (l tl o strata 6, 5, 4, 3, 2, 1 on the left of the figure foll in an inverted order, 1, 2, 3, 4, 5, 6, on the the fold; and the strata in the latter series are

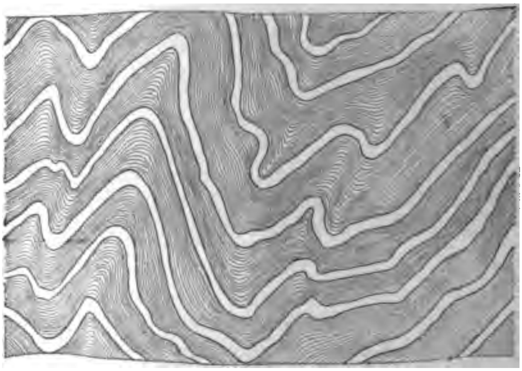


FIG. 204.—CONTORTED STRATIFICATION OF SCHISTS IN WESTCHESTER CO., N. Y. (Dana.)

Plication, Crumpling, Contortion. In many regions strata are not only tilted and folded, but wrinkled or plicated in an irregular and remarkable manner, as illustrated in Figs. 204 and 205. Such crumplings naturally suggest the exertion of enormous lateral pressure upon softened strata.

Conformability is parallelism of the sedimentary planes of strata. When the dip of a formation is different from that of a formation on which it is superimposed, the two are *unconformable.* Generally the lower formation has the greatest dip; and this demonstrates that it has experienced at least one more upthrow than the overlying formation (Figs. 293, 107, 298). Sedimentation over a surface rendered irregular by previous wearing results also in a species of unconformability known as a *break*, or a breach of stratigraphical continuity. (Figs. 302, 298.)

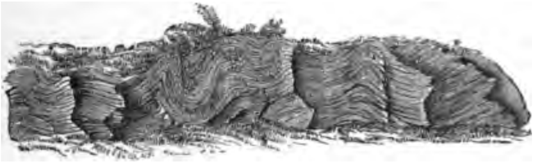


FIG. 205.—CONTORTED STRATA OF POTSDAM SANDSTONE IN ST. LAWRENCE COUNTY, N. Y. (Emmons.)

4. **Erosion of Strata.** All rocks exposed to the action of the elements undergo continued wastage. Their exposed surfaces disappear through solution or disintegration. The rate of disappearance depends on the intensity of the action and the power of the rock to resist it. Hence the wear is irregular, and in the course of geologic cycles very striking results have been produced. Some of these are illustrated in Figs. 75, 83, 32, 35.

Denudation is the wasting away of the rocks through the action of the elements, aided sometimes by extraordinary geological action, like earthquakes, floods, and lava torrents.

Circumdenudation is a wasting on all sides of a mass of rocks, leaving it to stand at or near its original altitude, while the surrounding rock masses have been removed.

An *Outlier* is an outstanding mass of rocks resulting from circumdenudation. Figs. 35, 355, 301.

Erosion, in the more special sense, refers to mechanical action localized along a river valley or sea or lake coast.

Corrasion is that part of erosion which results from the impact of transported materials against the surfaces undergoing erosion.

§ 3. Conditions of Unstratified Rocks.

1. **The Erupted Condition.** The state of rock material which has issued in a molten condition through rents in the earth's crust, like lavas from modern or ancient volcanoes, or lava-like materials from ancient fissures and rents. Descriptions have been given in Study XXIII of several important examples. The *basaltic structure* belongs to erupted rocks. It consists in closely fitting polygonal prisms of basalt, of which some notable examples exist in the "Giant's Causeway" and "Fingal's Cave"; also on the banks of the Hudson and Columbia rivers.

Erupted beds are often overlaid by other erup b
later origin, giving a truly bedded structure, which m
confounded with sedimentary bedding. Volcanic beddi
especially on the slopes of volcanoes. The bedd
also common among the ashes and cinders ejected from v
openings, as in California and Washington. Some of t
glomerate beds of Keweenaw Point, Lake Superi , are
by some, but not by the latest writers, to be an
ejections, though interbedded with strata of undoubt
origin.

Amygdules. Small almond-shaped or eroidal
filled with infiltrated mineral matter of vario
one sort fills the cavity, and sometimes vari
introduced in successive concentric layers.
are amygdaloids. (Fig. 80.) They occur in t
ficial parts of anciently igneous formations. The
supposed to have been originally filled with st

Pseud-Amygdules. The mineral filling of ro by some means were enlarged beyond the dimensions of an original vapor vesicle; or even of cavities formed where no vapor vesicle existed. Sometimes these cavities run together.

Metasomatic Change. The displacement on a large scale of the chemical substances of the minerals constituting a rock, and the substitution of other chemical substances. The transformation of augite into uralitic hornblende (having the form of augite and cleavage of hornblende), so commonly observed in the Northwest, is part of such a process. Similarly we find chlorite, viridite, and other substances appearing as secondary products. By such and analogous changes the whole body of a formation may become changed. All *regional* metamorphism of stratified rocks is essentially of this character.

2. **The Intrusive Condition.** This term is commonly applied to the condition of rock material intruded in a molten state, between strata. This is illustrated in Fig. 46. The trachytic intrusions of the Henry Mountains are illustrations on a large scale. See Study XXIV, page 150.

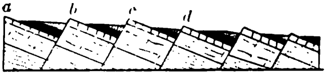
3. **The Vein Condition.** A *Vein*, in the general sense, is a fissure in the earth's crust filled with mineral matter different from that of the fissured rock (Figs. 96, 97, 98). When the fissure is straight and filled with matter injected in a molten state, it forms a dike (Figs. 77, 79, 83). When the filled fissure is more or less sinuous and irregular, it forms a vein in the more restricted sense. Such veins may be filled with granite, porphyry, or other rocks commonly reputed of the igneous class. (Fig. 46.) Most commonly, however, the filling of a true vein consists of layers of various mineral matters on the opposite walls, in corresponding succession (Figs. 99, 100). This subject is further elucidated in Study XXVII.

§ 5. Classification of Formations.

1. **Evidences of Relative Age.** (1) *From Superposition.* Evidently the sediments were originally laid down in the order of age. Unless subsequently overturned, the relative ages of the strata would be indicated by their order of superposition.

Cases exist, however, in which an upraised fold has been overturned on a vast scale. Here the ages of the strata on the under side of the fold must be the reverse of their order of superposition (Fig. 203). These circumstances create great difficulties for the practical geologist.

The faulting of strata, in some cases where the accident is concealed, gives rise to embarrassments in determining the true order of superposition. Here, in Fig. 206, the strata are faulted at *b m*, *c m*, *d m*, etc., so that the stratum, *a*, after dipping beneath the surface, is brought to the surface again at *b*, *c*, *d*, etc., and thus appears to be four or more different strata of the same kind.



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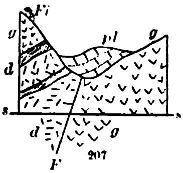

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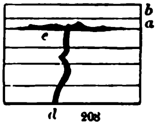

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FIG. 206—REPETITION OF STRATA BY FAULTING. Faulted limestone at Barnegat, Dutchess Co., N. Y. (Mather.)

FIG. 207—DEPOSITION SUBSEQUENT TO FORMATION OF DIKE OR FAULT. Section in Calabria. (Cortese.) *Fi*, Filadelfia. *g*, Granitic rocks. *d*, Dioritic rocks. *p'*, Pliocene strata. *F*, Fault intersecting the Apennines; older than the Pliocene epoch.

FIG. 208. DIKE AND OVERFLOW WITH SUBSEQUENT SEDIMENTATION. *d*, Dike. *e*, Overflow. *a*, *b*, Later sediments.

(2) *Evidence from Fossils.* Geological investigation has shown that the stratified formation of each successive period is characterized by particular fossil remains. Having learned by extensive observation what are the characteristic fossils of each formation, the discovery of any of these fossils may be taken as evidence of the age and position of the formation in which they occur. In general, the evidence of age when skilfully deduced from fossils, is considered next in value to that derived from observed superposition. But the value of palæontological evidence diminishes with the increase of distance between the localities compared, and with the divergence of the physical conditions under which the two faunas existed while living. The

nature of those conditions is indicated in part by the kind of rock holding the fossils.

(3) *Evidence from Intersections of Vein Matter.* It is at once intelligible that a vein or dike interrupted or cut off by another vein or dike existed before the one which cuts it off. On this principle, the chronological succession of a considerable number of dikes may sometimes be determined. A remarkable case is illustrated in Study XXVII, Fig. 98. In some cases a dike or fault may be seen intersecting the lower strata, but terminating before reaching the surface. In the case shown in Fig. 207, the evidence is that the dike or fault, *F*, is older than the formations *pl*, and *g* and *d* below *pl*. The proof of anteriority of a dike is clearer when there remains a mass of overflowed matter, *e*, Fig. 208, resting on the ancient surface and now included between the older strata and the later *a*, deposited upon it. In some cases, however, the molten matter *e* has been intruded between the strata after the deposition of the overlying strata, as in laccolitic mountains, Figs. 82, 83. Compare also the porphyry intrusions, Fig. 46.

(4) *Method of Combining the Observations.* Suppose careful determinations of strata have been made in many places. Suppose the various formations have been so studied and identified that, separately, each may be characterized and named. Suppose that in one region (1), as indicated in the annexed scheme, the formations studied may be designated E, F, G, H; in another (2), B, C, E, F, G; in another (3), A, L, M, N, O; in another (4), H, I, J, N; in another (5), B, D, K, M, and so on. Then, correlating these several series of strata, we should have them stand as shown in the columns headed (1), (2), (3), (4), (5). Obviously, then, the complete succession deducible from these collated series is that shown

(1)	(2)	(3)	(4)	(5)	VI
		A			A
	B			B	B
	C				C
				D	D
E	E				E
F	F				F
G	G				G
H			H		H
			I		I
			J		J
				K	K
		L			L
		M		M	M
		N	N		N
		O			O

in the column headed (VI). Now, wherever any formation, as F, is recognized by its fossils, or otherwise, we know its position in the complete series; and we know what should follow next above, and what next below. And whenever the succession is incomplete as in (1), we know the four newer formations are wanting; when it is like (2), we know the newest, and also formation D, are wanting; when like (3), we note a wide gap between A and L, and so on.

2. **The Cycle of Sedimentation.** The phenomena thus designated are also connected with the relative ages of strata.

CYCLES OF SEDIMENTATION.

Palæozoic Systems.	Coarse Fragmental.	Fine Fragmental.	Calcareous.	Calcareo-Fragmental.
UPPER CARB.	Parma Conglomerate.	Coal Measures. (Broken into many short epochs.)	Laramie Limestone.	Permian Group.
LOWER CARB.	Waverly Sandstone. (Marshall Phase.)	Waverly Group. (Chouteau Phase.)	Mountain Limestone.	False Coal Measures.
DEVONIAN.	Oriskany Sandstone.	Schoharie Grit.	Corniferous Limestone.	Hamilton Group, followed by Chemung.
SILURIAN.	Medina Sandstone. Oneida Conglomerate.	Niagara Shale. Clinton Group.	Niagara Limestone.	Salina Group.
CAMBRIAN.	Potsdam Sandstone.	Calciferous and Chazy.	Trenton Group.	Cincinnati Group.

It expresses the general fact that the series of strata is made up of repetitions of a smaller series; and the smaller series has below, a coarse fragmental member, followed by a fine fragmental member, and so on in fixed order, and terminating with a calcareous or calcareo-fragmental member. This order of succession is connected, as we shall hereafter see, with the periodical occurrence of greater and less energy in the processes of sedimentation. This order is not to be conceived as always sharply defined; but the general expression of it in the entire series of strata is sufficiently striking to be noted as a fact of geological significance. Anticipating the explanations of the names of formations, we here subjoin (page 268) a tabular exhibit of the large cycles realized in the succession of geological groups.

The oldest formation here, the Potsdam Sandstone, is placed, as usual, at the bottom. This is "coarse fragmental." At the right is placed the next following formation, the Calciferous and Chazy, and these together represent the "fine fragmental" member of the Cambrian Cycle. Next to the right stands the Trenton Group (proper), and this is the great "calcareous" member of this cycle. Finally, still further to the right, is the Cincinnati Group, which, as we shall see, is mixed calcareous and argillaceous, and thus stands for the last member of the cycle. The next formation in ascending order is the Oneida Conglomerate and Medina Sandstone. This is coarse fragmental again; and thus commences a new cycle. On its completion, a third cycle begins with the Oriskany Sandstone. Thus the whole Palæozoic series is composed of five Sedimentary Cycles. The explanation of the Cycle belongs to Dynamical Geology.

3. General Terms Employed in Classification. (1) *Categories of Time and Strata.* On such grounds as have been explained, the whole series of strata forming the stratified crust of the earth may be divided into general and subordinate assemblages. The object of the classification is to give expression to the history of events in the life of the earth. These events have been both inorganic and organic. There has been a series of transformations of the earth's physical aspect, and a corresponding series of transformations of the organic populations which have inhabited the surface. The only records of these great events are preserved in the rocks. They are a part of the rocks. The epochs of more energetic action in the transforming agencies have been marked by coarse fragmental deposits; the long periods of repose and luxuriance of organic production are symbolized by the great accumulations of limestone. The same events which changed the aspect of the physical world had some connection, at least, with changes in the aspect of the organic world. Thus a classification of the rocks is a marking off, also, of the stages in the history of life.

At certain epochs the lithological and palæontological breaks are found exceedingly profound. These divide the history of the world since sedimentation began, into a succession of grand Eras or Æons. Correspondingly, they give us the greater divisions in the succession of events. There are two conceptions in geological classification, *time* and *events*, and the events must correspond to the time. The rocks are the records of the events. So a grand division of time gives us a grand division of the rocks and a grand division in organic life. The general designations of these grand divisions are *Æon* (sometimes *Era*) in reference to time, and *Great System* in reference to strata. The type of organization corresponding has received no general designation. The divisions of an Æon are designated *Ages*, and the divisions of a *Great System* are generally known as *Systems*. So Ages are further divided into *Periods*, and Systems are divided into ***Groups***. When we carry the division farther, Periods are divided into *Epochs*, and Groups into *Stages*. This, at least, is the general system of nomenclature employed in this work, and conforms very closely with general usage in America. Attempts have been made by an International Geological Commission to unify the usage of different nations, but the recommendation of the Commission is unfortunately one not likely to command the acceptance of American geologists in consequence, partly, of its wholly needless changes in the use of terms.

We now arrange these general terms in their proper order of subordination for convenience of the student, repeating, for convenience of reference, the table on page 108.

Time Divisions.	*Rock Divisions.*	***Examples.***
ÆON.	GREAT SYSTEM.	**PALÆOZOIC, CÆNOZOIC.**
AGE.	SYSTEM.	**CAMBRIAN, TRIASSIC.**
Period.	Group.	**Niagara, Eocene.**
Epoch.	Stage.	**Calciferous, Champlain.**

Each of the different time divisions has its special designation as Eozoic, Palæozoic. The same special names apply to the corresponding rock divisions. So we may say "Cambrian Age" or "Cambrian System"; "Niagara Period" or "Niagara Group." But each special name can only be used for a certain category—an Æon or a Great System; an Age or a System, and so on. We should not say the "Cambrian Period" or "Cambrian Epoch"; the "Palæozoic Age" or "Palæozoic Period." This would be like giving the name of a class to an order or family. But this solecism is too frequently perpetrated even by our reputable writers. We shall even observe grosser negligence in employing time designations where rock designations are meant, as "The Trenton Period is composed of calcareous rocks," instead of "Trenton Group."

(2) *Stratigraphical Gaps.* It has already been abundantly shown, in Study XIX, that the complete series of formations underlies the earth's surface only in limited regions. In other regions, rocks belonging low in the series occupy the surface; or at least rocks formed long before the conclusion of the work of rock making. It often appears, also, that the series of formations under a particular region is deficient in more than the upper portion of the standard series. Some of the lower ones are found omitted, as illustrated in the columns (2), (3), (4), and (5) in the scheme on page 267. This forms a *Stratigraphical Gap.*

(3) *Geological Horizon.* We may, however, make out a statement of the complete series of formations. Then each formation stands in a particular place. That is its *horizon.* Wherever we recognize it, the same formations, save the occurrence of gaps, are always found above, and the same below.

(4) *Geological Equivalents.* Whenever we find the same geological horizon in two localities, however separated, the formations in the two regions are *equivalent.* Very likely the characters of the strata will be different. They may be even as different as sandstone and shale; but chronologically they are equivalent, and lie in the same geological horizon. Owing to the difference in the nature of the sediments, the species of molluscs included may be partially or even wholly different, and thus the

palæontological identification be defeated. Many such cases are known. We may then determine equivalency of horizons by a wide-extended study of orders of superposition, as illustrated in the scheme, page 267; or we may identify one or more conspicuous fossil types not observed in either locality to range above or below a particular stratum or formation; or finally, the experienced palæontologist may detect a particular *expression* in some of the fossils or in the collocation of the fossils in the two places, which will serve as an indication that the strata in those places belong in the same geological horizon.

(5) *Geological Synonyms.* The geology of the earth has been studied independently in different regions. Each investigator has determined the succession in his region; and unless he could certainly determine the equivalences between his formations and those of some earlier-studied region, has, according to custom, bestowed his own names upon them. These are ordinarily *geographical* designations. The name points to some *locality* where the formation can be advantageously studied. Now, in the course of time, it becomes certain that a formation named in one region is the equivalent of a certain formation differently named in another region. The two names are now synonyms. Thus, in some cases, we have acquired many names for the same geological horizon. This multitude of synonyms causes confusion for the student and the investigator; but it must not be complained of. The synonymy, for the greater part, affects only the subordinate divisions of the rocks and these are not here introduced.

(6) *The Law of Priority.* Geologists have agreed, in practice, not only that the most suitable names for formations are geographical, but that the one first proposed shall be accepted generally, and thus become a standard designation. But it is not allowable to take an old name which has been employed to embrace a certain range of strata, and subsequently employ it for a wider or narrower range, as is sometimes done by geologists in their use of the terms "Nashville Group" and "Waverly Group." Against either of these, as a designation of an assemblage of

strata wider or narrower than that originally designated, any name later proposed would hold the *right of priority.*

4. **Table of Geological Equivalents.** We will now arrange in a Table, the complete series of formations with their accepted classification, descending to the divisions called "periods" and "groups." Then, in parallel columns, we will insert the names of the equivalent formations as known in particular regions. We will select a few states in which investigations began at early periods, or were carried on without the possibility of certain connection with older studied states. To these will be added a column showing the principal English equivalents. The places left blank indicate what formations are wanting in the several regions.

REMARKS.—The student may take notice as follows: 1. The subdivisions of the Jurassic, standing in the column of American Standards, cannot be said to have come, as yet, into general use. 2. The Catskill Group is generally ranged under the Devonian. 3. The Waverly or Marshall is not generally placed in the horizon of the Catskill. For other remarks see Chapter V.

	American Standard.				Pennsylvania.	Ohio.	Michigan.
CÆNOZOIC.	QUARTERNARY.	22	Recent. Champlain. Glacial.		Recent. Champlain. Glacial.	Recent. Lacustrine. Glacial.	Recent. Lacustrine. Glacial.
	TERTIARY.	21	Equus Beds. Loup R. Gr.	Sumter.			
		20	Truckee. White R.	Yorktown.			
		19	Uinta. Bridger. Wahsatch.	Alabama.			
MESOZOIC.	CRETACEOUS.	18	Laramie. Fox Hills. Colorado. Dakota.				
	JURASSIC.	17	Flaming Gorge Gr. White Cliff Gr.				
	TRIASSIC.	16	Star Peak Gr. Koipato Gr.		Red Sandstone.		
PALÆOZOIC.		15	Permian.				
	UPPER CARBONIFEROUS.	14b	Coal Measures.		XIII. Coal Meas.	Coal Meas.	Coal Meas.
		14a	Conglomerate.		XII. Seral.	Homewood S.	Parma Cong.
	LOWER CARBONIFEROUS.	13	Carbonif. Lim.		XI. Umbral.	Maxville L.	Carbonif. Lim. Mich. Salt Gr.
			— NEW YORK. —				
		12	Catskill Gr.		X. Vespertine. IX. Ponent.	Waverly Gr.	Marshall Gr.
	DEVONIAN.	11	Chemung Gr.		VIII. Vergent.	Erie Shale.	Huron Gr.
		10	Hamilton Gr.		VIII. Cadent.	Huron Shale. Hamilton Gr.	Little Traverse.
		9	Corniferous Gr.		VIII. Post Merid.	Corniferous.	Mackinac Gr.
		8	Oriskany Gr.		VII. Meridian.	Oriskany.	
	SILURIAN.	7	Helderberg Gr.		VI. Premeridian.	Waterlime.	Waterlime.
		6	Salina Gr.		VI. Scalent.	Salina.	Salina.
		5	Niagara Gr.		V. Surgent. IV. Levant.	Niagara.	Niagara.
	CAMBRIAN.	4	Trenton Gr.		III. Matinal.	Trenton.	Trenton.
		3	Canadian Gr.		II. Auroral.	(Underlying.)	Canadian.
		2	Primordial Gr.		I. Primal.	(Underlying.)	L. Superior S.
EOZOIC.	HURONIAN.	1	Keweenian.				Keweenian.
							Huronian.
	LAURENTIAN.						Laurentian.

Canada.	Great Britain.	Europe.	Miscellaneous.
Recent. **Leda Clay or Erie Clay.** **Glacial.**	Recent. Pleistocene.	Recent.	Laterite. (India.)
	Pliocene or **English Crag.**	Pliocene — Sub-Apennine; Antwerp sands.	— Niobrara.
	Miocene.	Miocene — Faluns of Touraine; Upper Molasse.	
—	Oligocene.	Oligocene — Rupelian and Tongrian.	Vicksburg. Claiborne. Tejon, Cal.
	Eocene.	Eocene — Londinian; Parisian; Nummulitic.	
	Upper, { White, Gray. Middle, } Green Sand. Lower,	Danian. Senonian. Turonian. Cenomanian. Gault. Neocomian.	Chico, } Cal. (*Hiatus*) Shasta.
	Wealden. Oolite, { Upper, Middle, Lower. Lias.	Portlandian. Oxfordian. Bathonian. Toarcian, } Black Jura. Liasian, Sinemurian.	Atlantosaurus Beds. Baptanodon Beds.
	Rhætic Beds. Red Marls. Shell L. Variegated S.	Keuper. Muschelkalk. Bunter Sandstein.	Marnes irises. Calcaire coquillier. Gres bigarre.
	Marl Slate and L. Red Sandstones.	Zechstein. Rothliengendes.	Dyas (Europe).
Coal Meas.	Coal Meas.	Terrain houiller — Steinkohlen format.	Upper.
Bonaventure C.	Millstone Grit.	Flotzleer Sandstein.	Lower, { Lower of Rogers' Conglom. Meas.
	Mountain L.	Calcaire Carbonifere; Kohlenkalk; Kulm.	Mauch Chunk Shale (Pa.).
	Petherwin Gr. Old Red Sandst.		Kinderhook (Ill.); Chouteau L. (Mo.); Yellow S. (Iowa); Silicious Gr. (Tenn.), part.
Chemung. Sandstones of Gaspé.	Dartmouth Gr.	Cypridina Beds.	
Hamilton.	Plymouth Gr.	Eifel L.	
Corniferous.	Liskeard Gr.	Spirifer S.	
	Ludlow.		
Salina.	Wenlock.		
Niagara.	Upper Llandovery.		
Trenton.	Lower Llandovery.		
Canadian.	Caradoc and Bala. Llandeilo Flags.		
Primordial.	Arenig. Tremadoc Slate. Cambrian.		Up. { Tremadoc Sl. Lingula Flags. Low. { Menevian. Harlech and Longmynd. Cambrian.
Keweenian. **Huronian.** **Laurentian.**	Fundamental Gneiss.		

CHAPTER III.

DYNAMICAL GEOLOGY;

OR, WHAT HAS BEEN LEARNED ABOUT GEOLOGICAL AGENCIES.

We should now make some condensed statements respecting the forces, agencies, and methods of geological work. How have these physical results been accomplished to which our attention has thus far in this Part been turned? How have rocks originated? How have they been consolidated? How upturned, folded, and plicated? How metamorphosed? How have mountains been uplifted, valleys sunken, and the basins of the lakes and oceans scooped out? The explanation of these phenomena belongs to Dynamical Geology. We must restrict ourselves to very summary statements.

§ 1. Agency of Water.

1. **Running Water.** We begin with the action of running water, because its results are most familiar. The mere impact of rain drops on the surface disintegrates the soil and even the solid rocks. The dripping from the roofs of caves sometimes wears flutings in the stony walls. But rain water accumulated in torrents works sometimes with amazing energy. The destructive wear of any swollen stream is something which has attracted the notice of all. Most of the erosive work in sediment-bearing streams is by corrasion.

Every modern river flows in a valley, and the valley is simply a record of the river's erosive work. To what this in many cases amounts has been illustrated in Study XVI and elsewhere.

Where a stream is precipitated over a "fall," the reaction of the water at the foot gradually undermines the cliff, and it breaks down by degrees. This is more rapid than ordinary erosion.

Most high waterfalls are by such means in process of recession. As the recession continues, the foot of the fall gradually rises. Unless a fall, therefore, retreats up a rapid stream, its height must continually diminish, and at last the fall will be sloped off to a rapid chute.

Subterranean streams erode chiefly by solution and by friction of the water. A stream flowing through a fissure constantly enlarges it; but more especially if the fissure is in limestone. By such means caverns have been produced, some of which, like the Adelsberg and the Mammoth caverns, have become wonders of the world. The latter (Fig. 209) has many winding and mutually intersecting passages, which aggregate in length 150 miles. The diameter of the area covered by the cavern is 10 miles, and the main passage extends 4 miles. It is from 40 to 300 feet wide, and from 35 to 125 feet high.

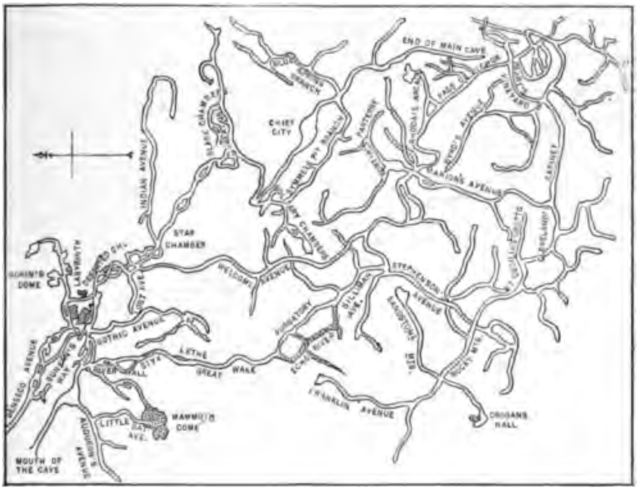


Fig. 209.—Plan of Mammoth Cave. (Hovey.)

The amount of sediment transported by great rivers is quite enormous. According to the investigations of Humphreys and Abbot, the *silt* carried to the Gulf of Mexico by the Mississippi River amounts to 1-1500th the weight of the water, or 1-2900th its bulk. This silt amounts, in other words, to 812,500,000,000,000 pounds per year, or a mass 1 mile square and 241 feet deep. Besides this, the Mississippi *pushes* along to the gulf an additional amount of mud, which, added to that floated, would form a mass a mile square and 268 feet deep. This amount removed annually from the whole basin of the Mississippi would lower it 1 foot in 4,920 years. Other great rivers accomplish equal or greater results. The Ganges lowers its basin by erosion 1 foot in 1,880 years.

The river sediments which find their way to the sea are widely dispersed over its bottom. The finer are transported to greatest distances; the coarser are deposited nearer the shore. Between the remote distances and the shore all grades of sediments are laid down. If the sediments have such density as to sink 10 feet an hour, and the motion of the water is 2 miles an hour, then the sediment would float 200 miles before settling 1,000 feet. Sediments of less fineness would float less distances. But while such suspension occurs in fresh waters, the same sediments in salt water would sink in 1-15th the time. Hence, as a fact, marine sediments would be deposited along a shore belt comparatively narrow, did not the agitation of the water near the surface prolong the period of suspension of a portion of the sediments.

River sediments also, at time of overflow, are more or less widely spread over the adjoining flood plain. Thus *alluvial* deposits are formed, which fill to a greater or less extent the rock-bottomed valley occupied by the river (Fig. 210). In this cut, *f f* is the level of the alluvial plain at a certain time. If subsequently the amount of water diminishes, *d c c′* becomes the level of the alluvial plain. By a further diminution, the flood plain is

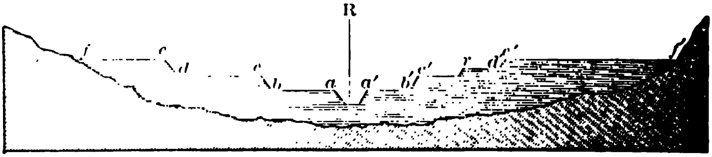


FIG. 210.—SECTION ACROSS A TERRACED RIVER VALLEY.

lowered to *b a a' b'*. These steps in the alluvial slope are *terraces*, due to different stages of the water. Sometimes two terraces occur on one side as the equivalent of a single one on the opposite side.

If, after a river has become established in its rocky bed, a subsidence takes place, sediment will accumulate underneath the channel, and the river will flow over a mud-formed bed. This has occurred with the river whose valley section is shown in the diagram. If afterward the bottom should be elevated, the mud would be scoured out.

The *bar* so commonly formed across the mouths of great rivers results from the sediment pushed into the sea. The development of the bar causes the extension of the *delta*. The Mississippi bar advances 338 feet annually over a width of 11,500 feet, and the delta has grown into a deep indentation in the shore line of the gulf. The whole area taken by the delta from the gulf is 12,300 square miles. This illustrates the nature of the work performed by the great rivers.

2. **Oceanic Action.** (1) *Ocean Currents.* These currents exert important agency in transporting any sediments which they float. The fine floating sediments of the Mississippi are borne hundreds of miles, and even to the Straits of Florida. The turbid water of the Amazons is traceable northward a very great distance. Generally these currents flow far from land, and contribute little to the process of erosion.

The bottom of the Atlantic, along the Arctic belt, reaching southward to a point 60 miles beyond Nantucket, is covered by a coarse gravel or sand; that of the great depths by a sticky mud. Under the Gulf Stream the bottom is of sand, of so fine a grain that the grains can only be distinguished under a microscope. Mixed with it are masses of minute shells. The two form a bed as level and hard as a floor. Bowlders are occasionally found, dropped, probably, from cakes of ice floating from shore.

(2) *Wave Action.* The waves reach the shore and exert a vast mechanical agency. Not only is the power great, but its

exertion is incessant. The highest waves are only about 43 feet above the bottom of the trough between them; but the force with which they sometimes strike a solid resistance is two or three tons to the square foot. Such force—or even the ordinary wave force during a winter (2,000 pounds per square foot)—exerted on an ordinary beach, must cause its rapid disintegration. Accordingly we learn that whole towns have been undermined, and many solid acres distributed over the ocean's bottom. *Tidal Waves* along shore act with similar energy. In straits, small bays, and estuaries, the rise of the tide sometimes amounts to 20, 30, or 50 feet, and it sweeps along with destructive force. The *bore* of the Hoogley (a mouth of the Ganges) and the *piroroco* of the Amazons are famous. In the Bay of Fundy the rise of the spring tides is sometimes 60 feet. Under the action of the waves, large continental areas have in times past been wasted; straits like Behring and Gibraltar have been cut; connections of land and water have been modified; climates have been changed, faunas and floras exterminated and replaced by others. Shore action, indeed, has been largely instrumental in that wastage of continental masses which is believed, in some cases, to have resulted in their total disappearance.

3. **Action of Ice.** The freezing of water held in the pores of rocks and minerals is a very powerful disintegrating agency. Fine aluminous limestones just from the quarry, when exposed to the action of a winter's frost, split into many pieces. Sandstones and granites crumble to sand. Crevices are pried asunder, and the most stubborn quartzites are slowly reduced to fragments.

Floating Ice in rivers acts as an efficient agent of corrasion. It carries also, in some cases, large volumes of sediment, and distributes seeds along the valley of the stream.

In the form of *Glaciers*, ice seems to have performed important work in ages past; and our small modern glaciers probably typify the modes of action of the ancient ones. A *Glacier* is a sheet of ice resting in a mountain valley. It resulted from accumulations of snow for years, unmelted by the summer's warmth.

The glacier stretches upward into the region of perpetual snow. Fig. 211 is a view of a couple of modern Alpine glaciers, des Bossons at the left and Tacconnay on the right, with Mont Blanc, the highest summit, in the centre. The glacier moves continually downward, and would encroach on the cultivated fields if the ice were not melted away at the foot. The Glacier des Bossons transported the bodies of the victims of an avalanche 27,500 feet in forty-one years, or about 670 feet a year. The Great Glacier of Alaska moves a quarter of a mile per annum, or twice as rapidly as Bossons. Many rocky fragments roll down on the glacier from the adjoining slopes. These, at last, are landed at the foot of the glacier, and there accumulate a *terminal moraine*, which is shown in the figure. A *lateral moraine* is accumulated, also, along each border. These unstratified accumulations of worn and rounded stones remind us of the bowlders in the ordinary Drift; and these moraines look like some of the Drift hills

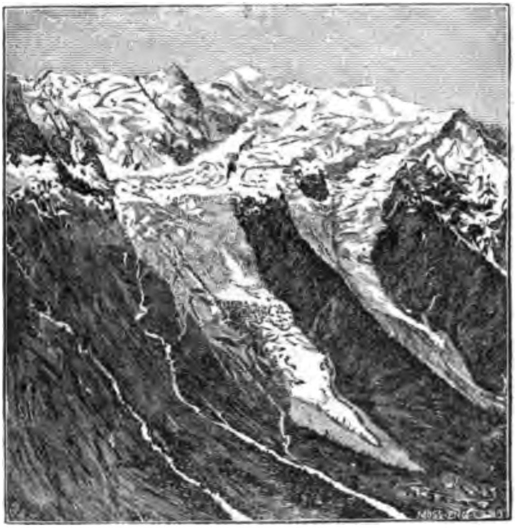


FIG. 211.—VIEW OF THE GLACIER DES BOSSONS AND MONT BLANC, FROM THE BRÉVENT, 8,000 FEET HIGH.

scattered over our Northern States. (Fig. 5.) The Alpine moraines, however, are destitute of all traces of stratification. (Fig. 212.)

Moreover, these glaciers by their motion leave scratches on the underlying rocky surfaces identical in appearance with those found on the bed rock throughout the Northern States. One of the anciently striated surfaces is shown in the adjoining cut, Fig. 213. This shows that the most flinty materials have yielded to the action which has grooved the ancient rock surfaces.

The surface of Greenland is completely covered by a modern glacier. A little depression of the summer temperature would

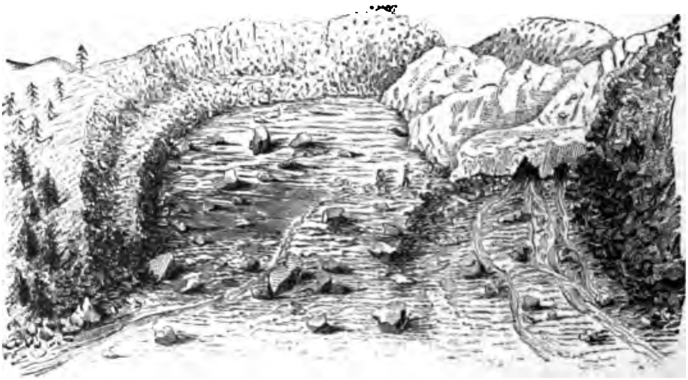


FIG. 212.—TERMINAL MORAINE AND BOWLDER-STREWN AREA AT THE FOOT OF THE MER DE GLACE. Compare the Bowlder-Covered Areas in Figs. 6 and 37.

extend the glaciated surface over part of North America. It is quite conceivable that without any great severity of cold, an ice covering might become permanent as far south as Chicago and Cleveland.

Glaciers exert powerful erosive action through the instrumentality of the sand and pebbles frozen into the bottom or pressed between the ice and the rock. Where the glacier is 1,000 feet thick, its pressure on the underlying rock is 4,870 pounds to the square foot. Corroborative evidence of the great grinding efficiency of glaciers is furnished by the stream of densely turbid water which issues at the foot. The stream which drains the Aar glacier brings down 280 tons per day, and the Justedal glacier of Norway wears down 60,000 cubic metres of rock annually.

A glacier mass reaching the sea, protrudes into it, is buoyed up by it, and finally broken off. The detached fragment then floats away as an *iceberg*, bearing with it mud and other *débris* from its northern home. The icebergs in the North Atlantic originate on the west coast of Greenland.

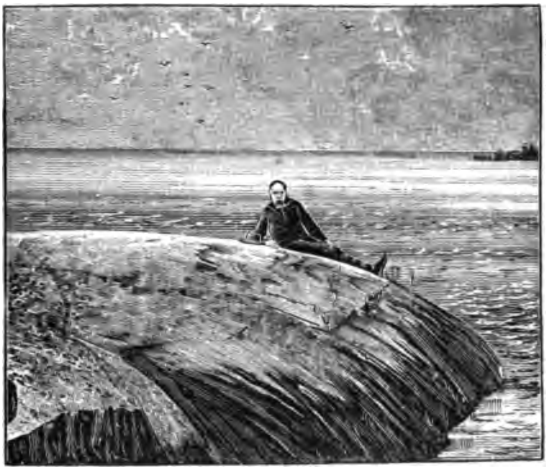


FIG. 213.—A STRIATED DOME OF QUARTZITE, FRAZER BAY, LAKE HURON. (Dr. E. Andrews.)

4. **Assortment of Marine Sediments.** Water and ice are thus agents for the creation and transportation of sediments, and their delivery in the sea. Borne by tides and currents, their unequal rates of deposition result in a complete assortment of the materials. At all times the sediment is coarser near the shore, and grows finer with distance. On this point Darwin has furnished some specific data, obtained between Santa Cruz and the Falkland Islands, on gradation in size of transported materials. These are cited below:

Miles from Shore.	*Depth in Fathoms.*	*Coarseness of Materials.*
2 to 4	11 to 12	Pebbles size of walnuts and smaller.
4 to 7	17 to 19	Do. size of hazel nuts.
10 to 11	23 to 25	.3 to .4 inch in diameter.
12	30 to 40	.2 inch in diameter.
22 to 150	45 to 65	.1 inch in diameter to fine sand.

At any point, however, the coarseness of the deposit depends on the rate of movement of the water. Should any cause increase at any place the transporting power of the water, coarser sediments would be dropped at this place, and the finer would be carried beyond. So the same spot would receive a graduated succession of sedimentary sheets. We should have there, in such case, a real *cycle of sedimentation.* This would be repeated as many times as the range of variation in the transporting power of the water should be repeated. Hence, probably, the cycle in the succession of rocky strata described on page 268.

§ 3. Agency of the Atmosphere.

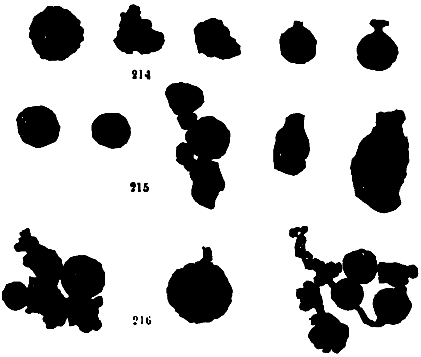
1. **Wear by Wind-borne Sands.** The ly
pheric action important to consider here is its tra
sands. Incidental to the movement of blown sa is
ing and *wearing* which result from the impinging
particles against hard surfaces. Quartzose bowl ,
more other rocks, become polished all over their exp
the actions extending equally to the bottoms of the
in the originally irregular surface. This effect ll ob
along the sand-covered eastern border of Lake ol
particularly on the sand-strewn plateau slope stre ing
from Sleeping Bear in Leelanau county. In the pass of
nardino, California, the granite is scratched like a
face (W. P. Blake). Very marked effects have
from the Gila, Amargosa, and Colorado deserts by New
Gilbert. On Cape Cod the driven sands even ind
the window panes. In the arts, steam-dri
etching and carving.

2. **Sand Dunes.** These are banks or hills of dry sand piled up by the wind. In the temperate zone the prevailing direction of the wind is westerly; hence the drifted sands have a resultant eastward movement, and thus they continue to travel, burying lands and houses and highways in their course. Along the eastern shores of our inland lakes, the sand which is thrown up by the waves is an exhaustless source. When dried, the wind drives it inland, forming banks and hills thirty to over a hundred feet high. At New Buffalo, on the eastern shore of Lake Michigan, the dunes measure 93 feet in height, and at Grand Haven they are 215 feet on the north side of Grand River and 205 feet on the south side. The track and station buildings of the Detroit and Milwaukee Railway, originally built on the north side, were so persistently encroached on by the sands that they were removed to the opposite side. At Sleeping Bear, the sands are drifting over a promontory 500 feet high. From the summit a wide waste of sand spreads over several square miles. Here and at Grand Haven, the singular spectacle is presented of a dead forest protruding its tree tops a few feet above the surface of the deluge of sand.

The dunes of England and the northern coasts of France, Denmark, and Russia have, in past times, made serious encroachments on human improvements. They have been the study of agriculturists and of scientific commissions, and at present a large degree of control is exercised over them.

We see no limit to the amount of sand which might thus be drifted, nor to the distance over which it might travel. Von Richthofen maintains that the great lœss deposits of China are mere beds of fine sand blown perhaps from the Mongolian desert; and Pumpelly inclines to accept a similar origin for the similar lœss beds of the valleys of the Mississippi, Missouri, Des Moines, and other rivers. Others, however, think them of fluviatile origin. If of æolian, or wind-borne, origin, some adequate source of supply must be pointed out. King has suggested that this may have been in the arid regions of the Cordilleras, where trains of dunes are still moving eastward, and must have moved in much greater abundance during the secular dry period of the Quaternary Age.

3. **Transportation of Volcanic Ashes.** The atmosphere exerts a similar agency in the transportation of volcanic "ashes," as already stated in connection with the phenomena of volcanoes (See Study XXIII). Dust from other sources, and even dust probably of cosmic origin, appears to be borne and sustained in the atmosphere almost indefinitely, destined at last to be brought down by precipitations of rain and snow. We present here grains of magnetic iron appearing to have been fused — probably the dust of a volatilized meteor.



Figs. 214, 215, 216.—Corpuscles of Magnetic Iron Believed to be of Cosmic Origin. × 500. (Tissandier.)
214—From the snow of Mont Blanc at the height of 2710 metres.
215—Collected from rain water at Sainte Marie du Mont.
216—From the dust collected in the unfrequented towers of Notre Dame, Paris.

§ 3. Agency of Heat.

In Studies XXII, XXIII, and XXIV numerous geological facts have been brought to view which point to the agency of heat. The phenomena of thermal springs, volcanoes, and ancient lavas are most naturally explained on the theory of a high internal temperature. The actual increase of heat experienced as we penetrate the earth is direct evidence that a high temperature prevails generally within one or two hundred miles of the earth's surface. As this interior heat is constantly escaping, there either must be some existing source of supply, or else, in ages past, we have ground to argue, a much higher temperature has existed within, and consequently has transmitted a much higher degree of thermal energy to the terrestrial surface. Probably both alternatives represent the facts.

If the earth is conceived as a cooling body, we must seek for the records of the action of heat at a former high temperature. These records would reveal (1) The consequences of the direct action of heat, and (2) The consequences of the slow abatement of the heat — especially the contraction incident to cooling.

1. Geological Results of Former High Temperature. (1.) *A Primitive Molten State.* If the primitive temperature of the earth was such as to reduce the entire globe to a state of fusion, then there was at some time a first crust — a *fire-formed crust.* On this the stratified sediments must eventually have accumulated. Later sediments we know accumulated in later ages, until we have in modern times a measured thickness of more than a hundred thousand feet of solid rocks. But these, according to modern views, are all of sedimentary origin, except an insignificant amount of erupted and intrusive rocks. What has become of the fire-formed crust? Can we expect ever to uncover it or penetrate to it as a fact of observation? We are persuaded it has long since disappeared.

If ocean sediments accumulated on the fire-formed crust, the first effect was to thicken the envelope within which the earth's internal heat was imprisoned. The previous thickness of the (fire-formed) crust was such as was demanded by the internal temperature and the thermal conducting power of the materials. With the sediments added, there was an excess of thickness, and the heat within would re-fuse the under layer of the igneous crust. So, much of it would disappear. The addition of further sediments would cause the loss of further portions from the under surface. This process would continue. At length the entire igneous crust would have disappeared, the molten central mass becoming inclosed by rocks which had been sea sediments. Nor is this the end. The process of eating away from the under side would continue even to the disappearance of the older portions of the sedimentary crust. How much of the sedimentary crust may thus have disappeared it is impossible to ascertain. The lowest strata ever observed are probably in position far above the oldest ever formed. We are quite at liberty to assume any such disappearance of oldest formed strata as facts of observation may suggest.

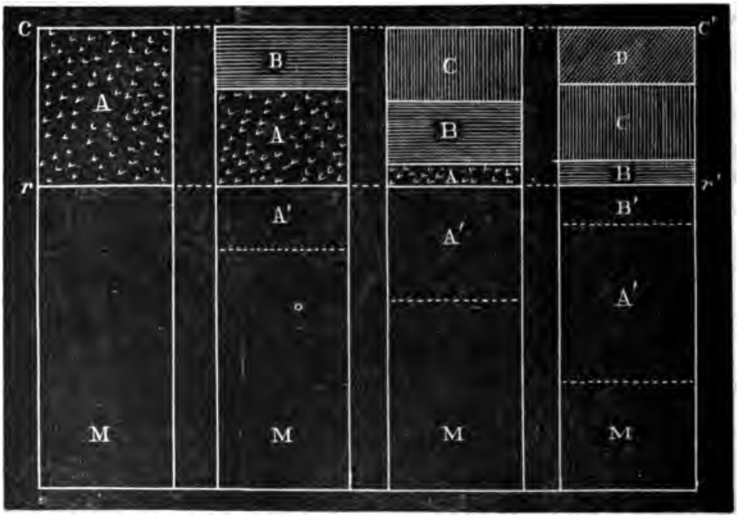


FIG. 217.—ASCENT OF ISOGEOTHERMAL PLANES IN THE EARTH'S CRUST.

The process of subterfusion of primitive portions of the crust is otherwise expressed as an ascent of the isogeothermal planes—the planes of equal temperature within the crust. The process is graphically illustrated by Fig. 217. The line *c c'* represents the bottom of the sea, on which sediments are accumulating. Evidences existing, to which reference will be made, that a load of sediments causes subsidence of the bottom, we may for convenience assume that the subsidence equals the filling, and the line *c c'* remains fixed. Then let *c r*, or *c' r'*, represent the constant thickness determined by the thermal conductivity of the crust materials. A, on the left, represents a section of the fire-formed crust, and M, a portion of the underlying molten matter. Then, as the successive additions, B, C, D, of sedimentary matter are made, successive portions A′, A′, of the fire-formed crust will be melted off. The total re-fused at successive intervals is shown at A′, A′, A′; while, in the last case, a portion, B′, of the sedimentary bed B has also disappeared.

It will be vain, therefore, to expect to see any of the primitive earth crust. It is equally vain to pretend that its non-discovery is any proof of its non-existence at the beginning of incrustation.

(2) *Origin of Erupted Material.* With this conception of a molten interior, it is easy to understand the origin of ancient or modern molten matter. In another connection we shall endeavor to point out the causes of its ascent to the surface. It seems probable, also, that the frequency of the outflows would be greatest in early times, when the crust was thinnest, and the progress of cooling most rapid.

(3) *Agency of Steam in Eruptive Action.* Some force acting upward with great energy reveals its existence in the eruption of thermal waters and volcanic ejecta. While steam may exert the eruptive force in the case of geysers, and to a collateral extent in volcanoes, there are reasons for believing that steam is not an adequate explanation of volcanic or seismic action. The presence of water beneath volcanoes is evinced not only by the usual abundance of steam, and the occasional volumes of mud thrown out, but also by the escape of the various constituents of sea water, such as chlorine, sulphurous acid, sulphur, common salt, iodine, and bromine. Some connection with the sea is implied, also, in the arrangement of lines of volcanic vents around the shores of the continents. The percolation of water to the deep, heated interior would produce results which are quite intelligible; and it is quite probable that some eruptions originate in this way. But the copious fissure outflows of geologic times must be otherwise explained.

(4) *Metamorphism.* During the ascent of the lower isogeo-

thermal planes into and through the sedimentary beds, as above explained, the latter were subjected to the intense action of heat. This action grew more and more intense in any particular one of the older beds, until it was reached by the plane of fusing temperature, when, of course, it became merged in the general molten mass. With the heat was also all the water which could percolate through the rocks. If, at a sufficient depth, the water was converted to steam, and driven toward the surface, it must be remembered that deep-seated water was subjected to enormous pressure, and retained its fluid state to a temperature far above 212° Fahr. Without doubt, much of the water saturating the deep rocks had a temperature of 300° to 800°. Here, then, were the conditions of intense chemical action, and of other important molecular changes. The experiments of Daubrée and others show that under such conditions rocks become softened and plastic, the molecules of matter enter into new arrangements, and out of the same stuff very different minerals and rock masses come into existence. Thus, earthy shales become slates, or even mica-schists; limestones become marbles. The lines of sedimentation become obliterated, and traces of fossils disappear. This result, in the aggregate, is *metamorphism*.

Its progress may be traced in the changes of the m
stituents of the rock. The molecules which, for i e,
so arranged as to constitute a crystal of augite, re
selves so as to form the mineral hornblende. The p e or
old crystal remains — a mould, having the crystall f
augite — but the mould is now filled with a substance wl
free to crystallize by itself, would not take the form in w
has become moulded. It is a *pseudomorph*. It has the
of one mineral, and the form of another. This hornbl le
pseudomorph after augite. In a similar way, pyro
times altered to talc. So, also, the anhydrous
cates, chrysolite, pyroxene, and chondrodite, have be
found changed to the hydrous magnesian silicate,
Other cases are well known. When the pseudom
constituents of a rock involves the chief mass, so tl

itself is altered, the change is known as *pseudomorphic metamorphism*, or *metasomatism*. Serpentine rock and the talcitic rock rensselærite are examples.

Regional Metamorphism is that which takes place over a wide area under some general terrestrial influence as just explained. *Local Metamorphism* is caused by the heat accompanying the eruption of molten material through a fissure. The immediate neighborhood of a dike is generally metamorphosed.

(5) *The Filling of Veins.* The filling of true banded mineral veins probably depends on the action of heat and water. These are powerful agents of solution. When such solutions find their way into the cooler parts of a fissure, precipitation begins. Layer after layer is deposited, probably at secular intervals, on the fissure walls. The nature of the deposit must vary with the nature of the solution and this will vary with the source from which the solution proceeds. When precipitation takes place it will form simultaneously on the two walls of the fissure; hence the symmetry of the arrangement (see Figs. 99 and 100). Possibly some veins are filled by a process of *sublimation*, under the action of dry heat. Many dikes are undoubtedly filled with matter in a state of fusion. But it is worth while to remember that the action of heat and water must reduce the deep-seated rocks on a large scale to a plastic condition, and that such rocks are necessarily subjected to enormous pressure. If, then, a fissure is opened to them or through them, such plastic substances must be squeezed in. Thus, apparently, many granite veins have originated, and perhaps also, some porphyritic and dioritic veins. An injected material has not therefore, of necessity, a molten origin.

2. **Effects of the Earth's Cooling.** (1) *Lateral Pressure.* Heretofore in considering the phenomena of mountains, Studies XXV and XXVI, we have discovered convincing proofs of the exertion of some great lateral pressure. On the theory of a cooling and contracting globe, we find an explanation of lateral pressure which, by the majority of geologists, is held to be the cause of crustal wrinkling and mountain development. It is, however,

often objected that the whole possible shrinkage in the circumference of the earth due to cooling from the temperature of first sedimentation to the present, would not be sufficient to yield the surplusage worked into the folds and plications which now exist in the crust. This objection acquires weight from the calculations of Fisher and Dutton, and from the studies of Claypole on the considerable amount of shortening supposed to have taken place in a section through the Appalachians. But it is certain that cooling and consequent shrinkage must have developed enormous lateral pressure, and it is eminently probable that this pressure found relief in wrinkles and plications. If the amount of surplusage afforded by this means is insufficient, we shall presently cite another source of surplusage which may adequately supplement this one.

(2) *Evolution of Heat.* Enormous lateral pressure resulting from the earth's contraction would necessarily produce more or less motion of the parts of the crust. The motion would be accompanied by friction, and this would evolve very considerable amounts of heat. Mallet has shown that the crushing of small cubes of various kinds of rocks may be made to raise the temperature to the melting point. Much more would the crushing pressure resulting from the earth's contraction. Mallet and others have conceived that the chief part of the earth's internal heat may have a mechanical origin. This suggestion implies the nonexistence of a molten core, and, in fact, the diminution of heat toward the centre. But we think that while the crushing action would develop much heat, this cause is not adequate to produce results on such a scale as the facts of geology seem to require. The whole earth has moved forward in all its continental regions with a harmonious and synchronous development. This would not be unless all parts were in physical sympathy with each other; and we cannot well conceive a more probable way in which such sympathy could exist than through a state of general plasticity or fusion.

(3) *Seismic Results of Contraction.* Different parts of the earth's crust must be conceived as possessing different degrees of

strength and rigidity. This would result from different rock-materials, mixed in different proportions, differently metamorphosed, and eventually resting in different positions. A strain, therefore, under which one part would yield, would be resisted by another part. The stress would be accumulated in the most rigid parts. But no rigidity and no materials could resist all stresses resulting from the action of the earth's mass. Every part must finally yield. In proportion as the stress was great, the final shock must be great. The shock is an earthquake movement. It transmits a tremor or vibration through the crust, and this may be felt to a great distance from the seat of the main collapse. The frequent earthquake tremors, therefore, are in part, merely the incidents of the slow contraction of the earth.

(4) *Mountain Making.* The principal phenomena of mountains which theory must seek to explain are as follows: (*a*) The elevation; (*b*) the folding and plication of the strata; (*c*) the faulting; (*d*) the accompanying heat and metamorphism; (*e*) the great thickening of the mountain strata; (*f*) the more fragmental character of the strata; (*g*) the elongation of the mountain uplift; (*h*) the direction of the elongation.

Much study has been bestowed on the explanation of these phenomena, and some principles have been generally agreed upon which we will here concisely state.

There must have been always, since the ocean existed, a system of ocean currents. There must also have been mineral material held in suspension in the sea water and moved along with the currents. There must also have been coarser materials rolled and pushed along. Some of this matter was simply of chemical precipitation; some resulted from disintegration of shells and corals; but the most bulky part was detrital. As soon as the continental masses rose within reach of the action of the waves and currents, mechanical sediments existed, and these were transported by the currents. The currents, while originating in astronomical causes, were greatly deflected and controlled by continental shores, and even by continental masses while yet in the germ beneath sea level. Supplies of detrital material therefore, furnished from any source, might be moved — partly by flotation and partly by rolling and pushing — for great distances along the line of an ocean current. In the course of ages, the accumulation of sediment along this line would so load the sea bottom that subsidence would result. The accumulation proceeded step by step with the subsidence. Sediments were accumulating on other parts of the sea bottom, but not so copiously, nor in so coarsely fragmental a condition; for elsewhere the transporting power of the water was less.

The downward protrusion of the sinking sea bottom exposed the deepest portion to the fusing and metamorphic action of the internal heat. The semifusion and softening of the deeper portion, and perhaps the comparative freshness and unsolidity of the upper portion made the line of subsidence a belt of weakness. We are not in this connection to conceive any actual considerable downward protrusion along the sinking region. The progress was slow. The protruding portion was progressively melted off. A nearly uniform thickness of the crust was maintained, though along this synclinal the exceptional condition of the materials developed exceptional lack of rigidity.

Accordingly, when in the progress of contraction, accumulated strains became too great for the crust to withstand, the yielding, the disturbance, the upfolding would take place along the enfeebled synclinal — synclinal in its texture more than in its form. Here a fold would rise. Here a mashing together of the softened materials would take place. Here the lateral pressure would most plicate the plastic sheets of sediments. Here, in this belt of weakness, would be developed the motion due to the contraction that had taken place over broad areas on either side. Here the sea water would find freest access, and here the heat, most readily transmitted from below, and most abundantly generated by most extensive motion, would work most extensive metamorphism.

Thus a great synclinal fold became mashed together and uplifted into an anticlinal mountain elevation. This was the completion of a *synclinorium* — a mountain system originating in a submarine synclinal. During the severe ordeal great fractures must have resulted, and great faultings must frequently have been produced. We have, then, in this account, an explanation which covers all the demands of mountain phenomena, except the linear forms and the direction of the trend; and these we think due to other causes, to be mentioned in another section.

The weight of the uplifted synclinorium exerted on each side an extraordinary lateral pressure. There existed, consequently, a tendency to the uprise of other ridges parallel with the first. When, in a later age, the crust must yield again, one or more broad but lower folds would rise alongside of the primitive uplift. Thus, from the central and highest crest to the remotest parallel fold on either side, and the plains beyond, a general descent in the extension of the strata constitutes a *geanticlinal;* and the meeting of two geanticlinal slopes in the broad valley between two mountain systems forms a *geosynclinal.* Mountain folds thus raised are destined to be materially lowered in altitude and changed in contour by the erosions of subsequent periods.

§ 5. Geological Climates.

1. **Terrestrial Causes.** (1) *Greater Heat and Greater Uniformity of Primitive Climates.* The progressive cooling of the earth has resulted, necessarily, in a progressive subsidence of the surface temperature. Heat from the sun and heat from beneath the crust are two chief factors in terrestrial climates. The solar heat at any point varies with the inclination of the solar rays. The influence of internal heat is the same in all latitudes and at all seasons. When the crust was thinner this influence was greater, and hence climatic uniformity was greater. The greater uniformity extended through the year and over all latitudes. When, therefore, the mean surface temperature was higher, it was also more uniform. Tropical climates prevailed at the poles as well as at the equator. This deduction is sustained by the facts of palæontology.

(2) *Alleged Antecedent Habitability of Northern Regions.* In the earth's cooling from a molten state the diminution of sur-

face heat would be nearly equal on all sides. But the solar rays would retard the surface cooling to a greater extent in the equatorial regions than in the polar. Consequently, the polar regions would first attain a habitable temperature. Chiefly on this ground G. H. Scribner has argued that life began at the pole. On this and other grounds President W. F. Warren has recently maintained that the site of Paradise was at the North Pole. Geology points out the fact that the north polar regions were once the site of a luxuriant fauna and flora; that many organic types appear to have emigrated from the north, and that many remaining there are degenerate forms; and science and tradition afford other support for this startling doctrine. We cannot yet, however, announce it as a principle in geological history. It may safely be asserted, however, that the principle cited lends no support to the theory that the first representatives of our species made their advent at the pole. At the epoch of man's advent, even if we fix it in Tertiary Time, the earth's geological progress was so far advanced that the polar climate had already become inhospitable; and the location of the Paradise of our first parents at the North Pole is an inadmissible theory.

(3) *Ultimate Total Dissipation of Terrestrial Heat.* There is no store of heat in the earth so great as not to be ultimately exhausted. If the earth has not already wasted its original supply, the time will necessarily arrive when external sources must furnish the only supply. As a fact, the present stage of terrestrial cooling is so far advanced that the thickened crust reduces to an inconsiderable pittance all the heat now reaching the surface from the interior. Our climates already depend practically on heat from the sun.

(4) *Ultimate Extinction of the Sun.* But the sun itself is cooling, and his destiny is just as inevitable as that of the earth. We cannot, indeed, calculate the ages which must elapse before the sun's light and heat will cease to reach the earth. That depends on the sun's present temperature and the sun's mass and density. His temperature is not accurately known; but from the most trustworthy assumptions it has been calculated by New-

combe that the sun will be as dense as the earth in 12,000,000 years. These considerations point out an inevitable limit to the present order of things.

2. **Extra-Terrestrial Causes of Climates.** Geological observation shows that one or more periods of extraordinary cold have passed, in the history of the northern hemisphere. Much study has been bestowed on efforts to find a cause for such a vicissitude. The following suggestions have been made: (*a*) The radiating power of the sun has been less at certain periods; (*b*) The earth, with the sun and solar system have been transported through colder regions of space; (*c*) Diminished absorbent power of the atmosphere. These causes would affect the whole earth equally. The next two (not indeed extra-terrestrial) would affect only certain regions: (*d*) A different arrangement of the continental masses has caused a different distribution of warm and cold currents; (*e*) Northern elevation. The following would affect the northern and southern hemispheres alternately: (*f*) Variations in the amount of obliquity of the earth's axis to the plane of the ecliptic; (*g*) The precession of the equinoxes, or direction of the inclination of the earth's axis in reference to perihelion and aphelion; (*h*) The periodic increase in the eccentricity of the earth's orbit. We cannot afford the space even to explain the three astronomical theories last mentioned, and the others will be at once intelligible, or may be thought out by the student.

§ 6. Tidal Action in the Earth's History.

1. **Definitions.** A *tide*, in general terms, is the change produced in the form of a body by the attraction exerted by another body. Two spheres mutually attracting become mutually *prolate*. The form of each is a prolate spheroid, with its longer axis in the line passing through the two centres of gravity. The elevations of the prolate poles above the mean surface are the tides. The elevation of the pole opposite the tide-producing body is the *antitide*. The tide results from the fact that the nearer side of the tide bearer is more strongly attracted than the

centre; and the antitide from the fact that the centre is more strongly attracted than the farther side. In the annexed diagram, the tidal attraction is supposed to come from the side *a*. Then *a m* is the tidal, and *b n* the antitidal elevation, *c o* and *d p* are the tidal depressions. The tide raised in the ocean by the attractions of the moon and sun are well known. But it is not necessary that a liquid film should exist. It is not necessary that the tide-bearing body should be distinctly plastic. It has been shown that if the earth were as rigid as glass, the moon's attraction would raise a tide in it three-fifths as high as the tide in the water-covered earth; and if the earth were all steel, the tide would be still one-third as high as it is at present. The whole earth then yields to the lunar tidal attraction. There is no matter so rigid as not to be relatively plastic and yielding in the presence of the enormous forces exerted upon each other by the heavenly bodies.

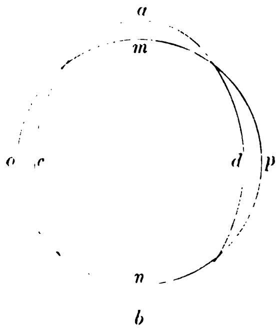


FIG. 218.—A DEFORMATIVE TIDE. *a m* is the tidal elevation; *b n*, the anti-tidal elevation; *c o* and *d p* are the tidal depressions.

2. **Seismic Consequences of Tidal Action.** From what has just been stated, it appears that the moon's attraction subjects the earth's crust to strains similar to those resulting from secular contraction. The moon must, therefore, contribute something to earthquake phenomena. There must, then, be a connection in times of occurrence between such phenomena and the phases of the moon. Accordingly, it has been shown, especially by M. Alexis Perrey, that these phenomena are of most frequent occurrence (*a*) When the moon is in perigee; (*b*) When the sun and moon are in conjunction or opposition, thus uniting their actions; (*c*) When the moon is near the meridian. It cannot be said, however, that tidal agency in earthquakes is fully established.

3. **Tidal Evolution of Heat.** It will at once occur to

the student that motions in the crust caused by tidal disturbance must evolve some heat, like the motions resulting from contraction. But we have not the requisite data as yet for determining whether or not the heat generated in this way is sufficient to explain all the thermal phenomena of the earth's crust, or even any important proportion of them. Here, however, are causes in action, and they must be borne in mind.

4. **Tidal Influence on Motions of the Earth and Moon.** (1) *Lagging of the Tide.* If the terrestrial tide responded instantly to the moon's attraction, the summit of the tide would be always under the moon. But owing to the viscosity even of fluid substances, the tide *lags.* That is, the moon is always farther west than the apex of the tide. In the accompanying figure, if Q is the earth's centre and C the position of the moon, then the apex of the lunar tide will be at B instead of A. That is, the rotation of the earth being in the direction of the arrow, it will have carried the point A to B while the tide is completing its rise after the culmination of the moon.

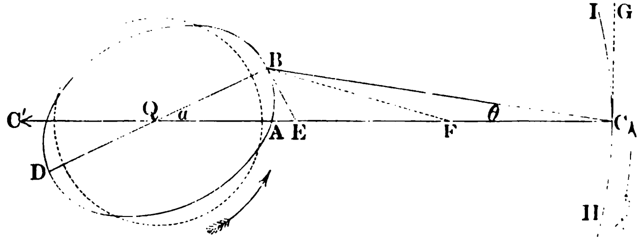


FIG. 219.—ILLUSTRATING A LAGGING TIDE.

(2) *Retardation of the Earth's Rotation.* Now, when the earth, the tide, and the moon are in the relative positions shown in Fig. 219, the moon's attraction on the tidal protuberance, in excess of its attraction on the more remote antitidal protuberance D, tends to turn the earth in a direction contrary to that of its actual rotation. That is, the earth's rotation is opposed. The length of the day is *increased.* Calculation shows that the amount of this increase is quite appreciable.

(3) *Diminution of the Earth's Oblateness.* This is a neces-

sary accompaniment of diminished velocity of rotation. This fact implies that the equatorial circumference of the earth has diminished, during long secular intervals of time, more than the polar circumference. Consequently, a greater lateral pressure has been experienced in the latitudinal (east and west) direction than in the longitudinal direction. This excess of latitudinal pressure would produce effects having a meridional trend; and this excess of equatorial shrinkage would supplement the shrinkage due to general contraction. The surplusage in the length of the circumference thus resulting, added to the surplusage resulting from general cooling contraction, might afford all the surplusage wrought into the folds and plications of the earth's crust, and thus obviate a difficulty in the theory of mountain making stated on page 292.

(4) *Increase of the Moon's Distance.* Referring again to Fig. 219, we may consider the reciprocal action of the tide B on the moon's motion in the orbit HI. This influence is plainly accelerative. But, if the moon's velocity is increased, its centrifugal tendency is increased. It therefore recedes from the earth and revolves in a larger orbit. These actions and reactions have existed as long as the earth and moon have existed as separate bodies. We must therefore contemplate a time when the moon was much nearer the earth than at present, and consequently revolved with a higher velocity.

5. **High Primitive Tides.** On these grounds, it been suggested by Professor Ball that in early times — during the Palæozoic Æon — the proximity of the mo enormously high tides in the oceans, and thus acce ed processes of erosion and deposition, and shortened c ingly the time required for the geological work accompl such increase of tidal action ever existed, the thick coarseness of the strata would testify to it. But the] strata appear to have been quietly deposited, under con not very different from those now existing. If we e: observations back through the Eozoic formations, we some evidences of superior energy in the geologic forces,

such indications of extreme violence as the suggestion of Professor Ball implies. Still, the reasoning is sound, and we are yet at liberty to conclude that extreme tidal energy left its record in those primordial sediments which have been in later times completely melted away.

6. **Ingrained Meridional Trends in the Earth's Crustal Structure.** Lunar tides existed on the earth while it was yet molten. They existed during the incrustive stage, and were more considerable than at present in proportion as the cube of the moon's distance was less. The superior density and viscosity of the molten fluid would, however, determine a lower tide than if produced in water. Recurring again to Fig. 219, it is seen that the moon tends to pull the lagging tide around toward the west. In a molten globe there would be some actual slipping westward. This would be greatest, on the average, along the equator. The effect of this slipping, on the forming crust, would be to impart a non-homogeneous structure. Lines of structure running nearly north and south would be ingrained in the crust. So much would result from lunar tidal action on the primitive crust.

But the slow subsidence of the equatorial protuberance during the secular diminution of the earth's rotational velocity, would produce a result of a similar nature. The excess of lateral pressure in the middle zone of the earth would be analogous to the action of the moon on the retarded tide. Any results produced would have a meridional trend. Meridional lines of structure would determine meridional predispositions to yield and take shape, under the action of any causes affecting the perfect symmetry of the earth's surface.

The lines of meridional structure and predisposition determined by these two causes were primordial features. Hence, if afterward, the secular cooling and contraction of the earth should tend to develop wrinkles without determinate direction, as would be the case, these meridional ingrained predispositions would give a majority of them a north and south direction. In the equatorial zone, the excess of east and west pressure would tend directly to produce meridional wrinkles. Thus we discover causes why the primitive mountains assumed elongated forms; and why the direction of the elongation was approximately north and south.

This theory is not claimed as one generally recognized among geologists. The suggestions are recent. But some causes operated to produce all the results enumerated on page 293 as mountain features to be explained by a final theory, and these views are submitted as at least plausible and deserving of study.

§ 7. Geotechtonic and Scenographic Results.

The dynamic actions which have given shape to the earth's periphery are strictly subjects of geological investigation. The results are inseparably bound up with the causes. The description of mountains, continents, oceans, and other physiographic features belongs to geology. Such descriptions may be gathered together under a separate head and designated "physical geography"; but so far physical geography is only a branch of geology. It is a grouping of a certain class of structural facts; but without the attempt to interpret them and ascertain their meaning and unity. Physical geography should be taught and understood as an essential part of geology.

It would be deeply interesting to review here the earth's physiographic features, and trace their connection with the causes that have been passed under review in this Chapter. The method of the First Part of this work, however, has led us continually to an observation of these features as the grounds and suggestions for the principles there induced. For the present, therefore, we shall pass on to other branches of the science which deserve prominent treatment.

CHAPTER IV.

PROGRESS OF TERRESTRIAL LIFE.

Definitions. Each Age and Period of the world's history has been characterized by its special assemblages of animals and plants. Many of the remains of these have been imbedded in the sediments of the time, and have become *fossilized.* When we examine to-day the rocks resulting from these sediments, the fossil forms are disclosed, and serve as the stamp of the age in which they were alive. Fossils are, therefore, a most important means for the determination of a formation. We shall not, in this course, attempt to lead the student far into this subject. We have shown, in Studies XXX–XXXIV, something about the method of studying fossils. In this chapter we propose to give, for convenient reference, an outline tabular exhibit of the *classification of fossils,* and sketch some of the most prominent fossil types which have appeared and disappeared in the history of life.

Fossilization. A *fossil* is whatever reproduces for us anything of the form or structure of an organic being no longer living. It may be: (1) The *real substance* of the organism, like a shell, or bone, so recent as to have been little altered. (2) The perfect form and structure of the organism, but with the original substance *replaced* by other mineral matter. This is a true *petrifaction.* The replacing mineral is commonly *calcite* or *silica;* sometimes *pyrites,* or other substance. In fossil wood it is frequently *opal.* (3) The fossil may be a mere *impression* of the exterior of the organism, made originally in the soft mud of the sea bottom. The shell, or coral, may be completely removed; but, with gutta-percha, putty, sulphur, or plaster, the *mould* may be filled, and the form of the original organism sometimes very perfectly restored.. In some cases the mould is found filled with stony matter. (4) The fossil may be a mere *cast* of the interior of a shell or other organism. The soft muddy or sandy filling of the interior became consolidated, and afterward the organism wasted away. Such casts often preserve very perfectly the muscular *scars* or *vascular impressions* on the interior of a shell.

Horizontal Range of Fossils. This is simply the geographical area over which a fossil species may be found. Some of the older species have been discovered in many different regions and countries. This wide range becomes of great service in identifying formations at remote points. The extent of the horizontal range depends on the extent of the uniformity of physical conditions when the animals lived. Diverse conditions at distant points necessitated diverse faunas. Thus it happens, sometimes, that equivalent formations hold different assemblages of fossils.

Vertical Range of Fossils. This refers to the occurrence of the same species, or other type, in formations older or newer, throughout a certain vertical range. It implies that a species survived changes in physical conditions which separated successive periods, and which exterminated most of its fellows. It implies that the physical changes were not great, or t t
species possessed great tenacity of life. Hence spec
great vertical range are generally, also, species of wide
ical distribution. As a rule, species are confined to a
formation. Sometimes they range vertically into one
higher formations. Sometimes, after disappearing fr
ing strata of changed constitution, a species reapp a
higher stratum formed under a recurrence of the for r ph
conditions. Its temporary disappearance indicates,
extinction, but *migration* to some more congenial r

Colonies, so called by Barrande, are in dents or mig
of faunas. A *colony* is an assemblage of f rep
teristic of a certain age, interstratified in a fo n
its own reputed characteristic fossils. Thus Bar
light in Bohemia a colony of Silurian fossils 8) feet
the midst of a Cambrian group. In such case it is e

the included colony is not properly characteristic of a different age. The colony, and the fauna in which it colonized, were contemporaneous, but living in different regions, separated by some barrier. The removal of this permitted the commingling of the two populations.

SECTION I—MOST IMPORTANT TYPES OF PLANTS AND ANIMALS.

[Numbers in parenthesis refer to Figures in this work.]

I.—PLANTS.

SERIES I.—(CRYPTOGAMS)

STEM I. THALLOPHYTES.—Consisting wholly of cellular tissue. Growing mostly in *fronds*, or other spreading forms, without proper stems or leaves.

CLASS I. ALGAE.—Those living in the sea are THALASSOPHYTES (295); those in fresh water, HYDROPHYTES.

ORDER I. UNICELLULAR THALLOPHYTES.—Including *Diatomaceæ*, of microscopic size, and having silicious shields. Other fossil Algæ are not thoroughly classified.

CLASS II. FUNGI.—**CLASS III. LICHENS.**—Not geologically important.

STEM II BRYOPHYTES—(*Anogens*).

CLASS I. MUSCINÆ.—Moss-like.

ORDER I. HEPATICÆ.—Liverworts. ORDER II. BRYOIDEÆ.—Mosses.

STEM III. PTERIDOPHYTES (*Acrogens*).—Vascular Cryptogams.

CLASS I. FILICACEÆ.—Ferns. The following Families are recognized:

Hymenophyllaceæ, Sphenopteridæ, Palæopteridæ, Neuropteridæ, Cardiopteridæ, Alethopteridæ, Pecopteridæ, Tæniopteridæ.

Also, from stems we have the genera *Caulopteris*, ***Megaphyium***, *Psaronius*.

CLASS II. RHIZOCARPEÆ.—Hydropterids.

CLASS III. CALAMARIEÆ.

Family 1. Equiseteæ.—Horse-tails. ***3. Calamiteæ.***—Calamites. ***4. Annularieæ.*** *Annularia, Asterophyllum, Sphenophyllum.*

CLASS IV. LYCOPODIACEÆ.

Family 1. *Lycopodieæ.* *Psilophyton.* ***2. Lepidodendreæ.*** *Lepidodendron, Ulodendron, Halonia.* ***4. Sigillarieæ.*** *Sigillaria, Stigmaria.*

SERIES II.—PHANEROGAMS.

STEM IV. GYMNOSPERMS.—Seed not inclosed.

ORDER I. CYCADACEÆ.—Carboniferous *Whittleseya* and many Mesozoic genera.

ORDER II. CORDAITEÆ.—*Cordaites.*

ORDER III. CONIFERÆ.—Pines, Firs, etc.

STEM V. ANGIOSPERMS.—Seed inclosed.

CLASS I. MONOCOTYLEDONS.—Endogens. Mostly parallel-veined leaves.

CLASS II. DICOTYLEDONS.—Exogens. Netted-veined leaves.

II.—ANIMALS.

STEM I.—PROTOZOA.

Chiefly microscopic, with no definite typical form, without specialized organs, and mostly with asexual, as well as sexual reproduction.

CLASS I. MONERA.—Of completely homogeneous, structureless protoplasm.

CLASS II. RHIZOPODA.—Body consisting chiefly of simple sarcode.

ORDER I FORAMINIFERA (Polythalamia).—Having a one-chambered or many-chambered shell, calcareous, rarely sandy, silicious, or chitinous.

SUB-ORDER I. IMPERFORATA.—Receptaculites. II. PERFORATA.—Globigerina, Nummulites, Orbitoides, Fusulina, Eozoön. (220, 222.)

ORDER II. RADIOLARIA (Polycistina). III. LOBOSA. *Amœba.* (221.)

STEM II.—CŒLENTERATA.

CLASS I. SPONGIÆ.—(Porifera. Amorphozoa.) Sponges.

CLASS II. ANTHOZOA. (Polypi. Zoöphyta.) Radiated, mostly with a calcareous skeleton, having radial septa. Skeleton known as coral.

ORDER I. ALCYONARIA.—(Octocoralla.) With eight radial divisions.

ORDER II. ZOANTHARIA.—Having twelve or more radial divisions. Most Palæozoic corals belong here.

SUB-ORDER ANTIPATHARIA.—Having an internal horny axis.

SUB-ORDER ACTINARIA.—Without calcareous skeleton. Not fossilized.

SUB-ORDER MADREPORARIA (Zoantharia Sclerodermata).—Having a calcareous skeleton.

Group 1. **Tetracoralla** (Rugosa).—Cup Corals. Four systems or fascicles of septa. See Studies XXX, XXXI.

Family 1. Inexpleta.—Interseptal chambers empty or with feeble dissepiments—tabulæ and cellular contents wanting. Septa well developed. Cyathiform, simple. *Amplexus* (114, 115, 118, 119).

Family 2. Expleta.—Tabulæ or cells or both fill the visceral cavity.

SUB-FAMILY DIAPHRAGMATOPHORA.—Tabulæ complete; cellular endotheca wanting or feebly developed. Septa regularly radiate. *Zaphrentis* (112, 113, 117), *Streptelasma* (122–124).

SUB-FAM. PLEONOPHORA.—Tabulæ incomplete, present only in central part of visceral cavity; cellular tissue in peripheral part. *Cyathophyllum* (116, 120, 121), *Heliophyllum* (130, 132, 133), *Acervularia* (138, 139), *Diphyphyllum* (141–143), *Lithostrotion* (140).

SUB-FAM. CYSTOPHORA.—Whole interior filled with vesicular tissue. *Cystiphyllum* (134–136).

✓ **Group 2. Hexacoralla.**—Septa mostly in multiples of six. Here belong the "honey-comb" corals.

Family 1. Poritidæ.—Compound, cells united, small. Septa few, mostly rudimentary. Walls perforated.

SUB-FAM. FAVOSITINÆ.—Massive, without cœnenchyma. Cells long, prismatic, divided by numerous tabulæ. Walls pierced by numerous perforations. Septa six or twelve, often reduced to mere longitudinal raised striæ on the walls. *Favosites* (144–149, 152), *Alveolites* (153, 154), *Limaria* (155, 156), *Cladopora* (157, 158).

✓ **CLASS III. HYDROMEDUSÆ** (Hydrozoa).—Hydras and Sea Nettles. Fixed, polyp-like, small, undivided by radial septa. Skeleton calcareous, chitinous, or wanting.

ORDER HYDROIDA (Hydrophora).

Family Stromatoporidæ.—[Probably a "comprehensive" type uniting characters of Foraminifera, Sponges, Hydroida, and Tetracoralla. Probably also *Eozoön* belongs in near relation] (223–227).

SUB-ORDER GRAPTOLITIDÆ.

STEM III.—(ECHINODERMATA.)

✓ **CLASS I. CRINOIDEA.**—Sea Lilies. Crinoids. Supported by a stem. Visceral organs inclosed by calcareous plates symmetrical in form and disposition. Five to ten arms spring from the border of the cup, and these are fringed with pinnules.

ORDER I. ENCRINOIDEA (Palæocrinoidea) (233).—Armed Sea Lilies. *Rhizocrinus* (232), *Forbesiocrinus* (234).

ORDER II. CYSTOIDEA.—Cystids. Short-stemmed or sessile. Arms feebly developed. Palæozoic. *Caryocrinus.*

ORDER III. BLASTOIDEA.—Nut shaped or oval, armless, short-stemmed. Cup of thirteen regularly disposed principal pieces. *Pentremites.*

√ **CLASS II. ASTEROIDEA.**—Sea Stars. Star Fishes.

√ **CLASS III. ECHINOIDEA.**—Sea Urchins.

√ **CLASS IV. HOLOTHUROIDEA.**—Sea Cucumbers. Holothurians.

STEM IV.—VERMES.

The four lower classes of Worms are scarcely known fossil.

CLASS ANNELIDA.—With cylindrical segmented body and chitinous integument. *Serpula, Spirorbis? Cornulites, Scolithus.*

STEM V.—MOLLUSCA.

DIVISION A.—MOLLUSCOIDEA.

√ **CLASS I. BRYOZOA** (Polyzoa).—Colonies of small animals surrounded by a membranous or calcified integument, and forming branched moss-like or membranous compound structures. In general aspect much resembling Hydrozoa.

Sub-Class I. Entoprocta.—No representatives fossil.

Sub-Class II. Ectoprocta.

Family 4. ***Fenestellidæ.***—*Fenestella, Polypora, Archimedes.*

Family 5. ***Ptilodictyonidæ.***—*Ptilodictya, Coscinium.*

Family 10. ***Chætetidæ.***—In masses resembling diminutive ***Favositidæ***, but without connecting pores. ***Monticulipora.***

√ **CLASS II. BRACHIOPODA** (Palliobranchiata).—Brachiopods. Compare Studies XXXIII and XXXIV.

ORDER I. PLEUROPYGIA.—Hinge structure and arm supports wanting.

Family 1. ***Lingulidæ.***—*Lingula, Lingulella, Lingulepis, Glottidia.*

Family 2. ***Obolidæ.***—*Obolus, Oboiella, Trematis.*

Family 3. ***Discinidæ.***—*Discina, Orbiculoidea.*

Family 4. ***Trimerellidæ.***—*Monomerella, Trimerella, Dinobolus.*

Family 5. ***Craniadæ.***—*Crania.*

ORDER II. APYGIA—Always calcareous, with hinge structure. With or without arm-supports.

Family 1. ***Productidæ.***—*Producta, Chonetes, Productella.*

Family 2. ***Strophomenidæ.***—*Orthis* (166, 171), *Streptorhynchus, Orthisina, Strophomena* (167, 168, 190, 192), *Leptæna, Tropidoleptus, Skenidium, Vitulina.*

Family 3. Koninckinidæ.—*Koninckia.* None American.

Family 4. Spiriferidæ.—*Spirifera* (161, 162, 164, 165, 172, 174), *Spiriferina, Cyrtia, Cyrtina* (170). *Syringothyris* (181, 183), *Sprigera* (179, 180), *Nucleospira, Merista, Meristella, Retzia, Uncites.*

Family 5. Atrypidæ.—*Atrypa* (175–177), *Cœlospira, Zygospira* (178)

Family 6. Rhynchonellidæ.—*Rhynchonella, Leiorhynchus, Dimerella, Camerella, Pentamerus, Stricklandia.*

Family 7. Stringocephalidæ.—*Stringocephalus.* None American.

Family 8. Thecideidæ.—*Thecia.* None American.

Family 9. Terebratulidæ.—*Terebratula* (184–186), *Cryptonella, Rensselæria, Meganteris, Centronella* (187, 188).

DIVISION B.—MOLLUSCA Proper.

√ **CLASS I. LAMELLIBRANCHIATA** (159, 160).—Equivalve Bivalves. See Study XXXIII.

ORDER I. ASIPHONIDA.—Mantle lobes divided, siphon wanting, pallial impression without sinus.

DIVISION A. MONOMYARIA.—Only one (hinder) adductor muscle. *Ostrea, Gryphæa, Exogyra, Pernopecten, Aviculopecten.*

DIVISION B. HETEROMYARIA.—Two unequal adductors. Cartilage separated in numerous isolated pits or furrows. *Avicula. Pterinea.*

DIVISION C. HOMOMYARIA.—Two equal adductors. *Cyrtodonta, Nucula, Palæoneilo, Schizodus, Cardinia.*

ORDER II. SIPHONIDA.—Siphon present; mantle lobes more or less united.

DIVISION A. INTEGRIPALLIATA.—Pallial impression without sinus. *Lucina, Conocardium, Cypricardinia, Sanguinolaria.*

DIVISION B. SINUPALLIATA.

Solenopsis, Cardiomorpha, Edmondia, Allorisma, Sanguinolites.

√ **CLASS II. GASTEROPODA** (Glossophora. Cephalophora).—Univalves.

Sub-Class I. Scaphopoda.—Tubular, open at both ends. *Dentalium.*

Sub-Class III. Gasteropoda Proper.

ORDER I. PROSOBRANCHIA.—Gills anterior to the heart. *Metoptoma, Bellerophon, Cyclonema, Holopea, Platyceras, Platyostoma, Loxonema.*

ORDER II. HETEROPODA.—Mostly naked. Unimportant palæontologically.

ORDER III. OPISTHOBRANCHIA.—Scarcely known as Palæozoic.

ORDER IV. PULMONATA.—Air-breathing. *Pupa, Dendropupa.*

Sub-Class IV. Pteropoda.—*Tentaculites, Hyolithes, Conularia.*

CLASS III. CEPHALOPODA (Cephalophora) Cephalopods.

ORDER TETRABRANCHIATA (236).—Having an external chambered shell.

SUB-ORDER I. NAUTILOIDEA.—Shell straight, bent, or coiled. Sutures mostly simple or slightly sinuate. Siphonal cornets directed backwards.

Family 1. Orthoceratidæ.—Straight or slightly bent. *Orthoceras.* (235, 237.)

Family 3. Cyrtoceratidæ.—Simply bent. *Cyrtoceras* (238), *Phragmoceras.*

Family 4. Nautilidæ.—Coiled in a plane. *Gyroceras* (239), *Lituites, Nautilus.*

Family 5. Trochoceratidæ.—Coiled in a conical spire. *Trochoceras.*

SUB-ORDER II. AMMONOIDEA (240).—Shell coiled variously or straight. Suture line undulate, lobed or foliaceous. Siphon cylindrical, marginal.

Family 1. Clymenidæ.—Umbilicus wide. Siphon internal. *Clymenia.*

Family 2. Goniatitidæ.—Siphon thick, external. *Goniatites.*

A large Sub-Order, but the remaining genera are post-Palæozoic.

STEM VI. ARTHROPODA.

CLASS I. CRUSTACEA.—Respiration aquatic. Exoskeleton chitinous or sub-calcareous.

Sub-Class II. Cirripedia.—Attached when adult.

Sub-Class III. Entomostraca.—Carapace horny, composed of one or more pieces.

ORDER I. OSTRACODA.—Carapace of two valves. *Leperditia, Cythere.*

ORDER IX. PHYLLOCARIDA.—Feet serving as gills. *Ceratiocaris.*

ORDER X. TRILOBITA (231).—Body more or less trilobed. Cephalic shield usually with a pair of sessile eyes. Thorax with movable segments, and caudal shield (pygidium) with consolidated segments. *Paradoxides* (228), *Dikellocephalus, Phacops, Calymene* (229, 230), *Proetus, Lichas, Acidaspis, Asaphus, Illænus.*

ORDER XI. MEROSTOMATA.
Eurypterus, *Pterygotus*.

Sub-Class IV. Malacostraca.

CLASS II. ARACHNIDA.— Scorpions and Spiders.

ORDER I PEDIPALPI.— Scorpions. Abdomen distinctly segmented.

ORDER II. ARANEIDA.— Spiders. Head and thorax consolidated.

CLASS III. MYRIAPODA.— Myriapods. *Xylobius*, *Archiulus*.

CLASS IV. INSECTA.

STEM VII. VERTEBRATA.

CLASS I. PISCES.— Fishes.

ORDER I. TELEOSTEI.— Common bony fishes. Not Palæozoic.

ORDER II. GANOIDEI.— Endoskeleton generally only partially ossified. Exoskeleton in the form of ganoid scales, plates, or spines. Caudal fin mostly unsymmetrical or "heterocercal", but sometimes "homocercal."

DIVISION I. LEPIDOGANOIDEI.— Exoskeleton of scales of moderate size. Endoskeleton partly ossified. ***Palæoniscus***, *Onychodus* (242), *Lepidosteus* (249–251).

DIVISION II. PLACOGANOIDEI.— Head and more or less of the body protected by large ganoid plates. *Cephalaspis* (245), *Pterichthys* (244), *Coccosteus* (246), *Bothriolepis* (247), *Scaphaspis*, *Palæaspis*, *Dinichthys* (241).

ORDER III. ELASMOBRANCHII (Selachia, Placoidei).— Sharks, Rays, and Chimæræ. Skull and lower jaw well developed, but no cranial bones. Vertebral column cartilaginous. Exoskeleton placoid, consisting of grains or tubercles.

SUB-ORDER I. HOLOCEPHALI.—Jaws covered by broad plates.

SUB-ORDER II. PLAGIOSTOMI.— Sharks and Rays.

SECTION I. CESTRAPHORI (243).— Back teeth obtuse. *Acrodus*, *Onchus*.

SECTION II. SELACHII — True Sharks and Dog Fishes.

SECTION III. BATIDES.— Rays and Skates. Body transversely flattened.

ORDER IV. DIPNOI (Protopteri).— Notochord persistent. *Ceratodus*.

CLASS II. AMPHIBIA.— Frogs, Toads, Salamanders, Cœcilians, and extinct Labyrinthodonts.

ORDER I. URODELA (Ichthyomorpha).— Tailed Amphibians. Not earlier than Permian.

ORDER II. ANOURA (Batrachia. Theriomorpha).—Frogs and Toads or Tailless Amphibians. Not known earlier than Tertiary.

ORDER IV. LABYRINTHODONTA.—All extinct. Salamandriform. Protected with sculptured bony plates. Teeth with "labyrinthine" structure.

Section I. Euglypta.—Cranial bones strongly sculptured. *Labyrinthodon.*

Section VI. Ganocephala (Archegosauria).—Vertebral column notochordal. *Archegosaurus, Trimerorachis, Rachitomus, Eryops, Amphibamus.*

Section X. Microsauria.—Ossification of limbs incomplete. *Dendrerpeton, Hylonomus, Hylerpeton, Sauropus.*

Other American Labyrinthodonts: *Tuditanus, Leptophractus, Pelion, Baphetes, Colletosaurus, Dictyocephalus, Cricotus.*

CLASS III. REPTILIA.

ORDER I. CHELONIA.—Turtles and Tortoises. All post-Palæozoic.

ORDER II. PLESIOSAURIA (Sauropterygia).—Head small and neck long. *Plesiosaurus* (254), *Nothosaurus, Simosaurus, Pliosaurus, Elasmosaurus* (255), *Cimoliosaurus.*

ORDER III. LACERTILIA.—Lizards. *Telerpeton, Centemodon.*

ORDER IV. PYTHONOMORPHA (Mososauria).—Body very elongate. *Mososaurus, Leiodon, Tylosaurus, Lestosaurus* (256), *Clidastes,* all Cretaceous.

ORDER V. OPHIDIA.—Serpents. *Palæophis, Boavus, Limnophis.*

ORDER VI. ICHTHYOSAURIA (Ichthyopterygia).—Marine. *Ichthyosaurus* (252).

ORDER VII. BAPTANODONTA.—Like *Ichthyosaurus,* but without teeth. *Baptanodon* (253).

ORDER VIII. CROCODILIA.—Crocodiles, Alligators, and Gavials.

ORDER IX. DICYNODONTIA.—Jaws beak-like, resembling Turtles. *Oudenodon* (263), *Dicynodon* (264).

ORDER X. THERIODONTA.—Dentition of carnivorous type. *Cynodraco* (262), *Lycosaurus* (261).

ORDER XI. PTEROSAURIA.—Flying Saurians. *Pterodactylus* (265), *Pteranodon, Dimorphodon* (266).

Sub-Class Dinosauria (according to Marsh).

ORDER I. SAUROPODA.—Herbivores. Premaxillaries with teeth. Plantigrade.

Families: ***Atlantosauridæ, Diplodocidæ, Morosauridæ.***

ORDER II. STEGOSAURIA.—Plated Lizards. Herbivorous. Post-pubic present.

Families: ***Stegosauridæ, Scelidosauridæ.***

ORDER III. ORNITHOPODA.—Feet bird-like. Herbivorous.

Families: ***Camptonotidæ, Iguanodontidæ*** (258–260), ***Hadrosauridæ*** (258).

ORDER IV. THEROPODA.—Beast-footed. Carnivorous.

Families: ***Megalosauridæ, Labrosauridæ, Zanclodontidæ, Amphisauridæ.***

Also SUB-ORDERS: CŒLURIA, COMPSOGNATHA, CERATOSAURIA.

✓ **CLASS IV. AVES.**—Birds.

Sub-Class I. Odontornithes.—Birds with teeth [according to Marsh].

ORDER I. ODONTOLCÆ.—Teeth in grooves. *Hesperornis* (269-271).

ORDER II. ODONTOTORMÆ.—Teeth in sockets. *Ichthyornis* (268), *Apatornis.*

ORDER III. SAURURÆ.—Teeth. Tail longer than body. *Archæopteryx* (267).

Sub-Class II. Ratitæ.—Sternum without a prominent keel.

Sub-Class III. Carinatæ.—Sternum with a prominent keel. Ordinary birds.

✓ **CLASS V. MAMMALIA.**

✓ **Sub-Class I. Ornithodelphia** (Monotremata).—Oviparous.

✓ **Sub-Class II. Didelphia** (Marsupialia).—Pouched Mammals (272-277). Possum

DIVISIONS: DIPROTODONTIA, POLYPROTODONTIA.

✓ **Sub-Class III. Monodelphia** (Eutheria).—Placental Mammals.

ORDER I. EDENTATA. SUB-ORDERS: PHYTOPHAGA, ENTOMOPHAGA.

ORDER II. SIRENIA.—Manatee and Dugong.

ORDER III. CETACEA.—Whales, Dolphins, and Porpoises.

Families: ***Balænidæ, Catodontidæ, Delphinidæ, Rhynchoceti, Zeuglodontidæ.***

SUPER-ORDER UNGULATA.—Hoofed Mammals [according to Marsh].

ORDER I. HYRACOIDEA.—No canines. *Hyracotherium, Hyracodon.*

ORDER II. PROBOSCIDEA.—Elephantine Mammals. *Elephas, Mastodon, Dinotherium* (289).

ORDER III. AMBLYDACTYLA (Amblypoda, Cope).—A theoretical type from which diverged two sub-orders, DINOCERATA and CORYPHODONTIA, the former with *Uintatherium* (284, 285), *Dionceras* (286), *Tinoceras* (287); the latter with *Coryphodon* (Bathmodon) (278-280).

ORDER IV. CLINODACTYLA.

SUB-ORDER I. MESAXONIA (Perissodactyla).—Generally odd-toed.

Families: ***Rhinoceridæ, Tapiridæ, Lymnohyidæ, Brontotheridæ*** (288), ***Palæotheridæ, Machrauchenidæ, Equidæ*** (290).

SUB-ORDER II. PARAXONIA (Artiodactyla).—Mostly even-toed.

DIVISION I. OMNIVORA, with ***Families:*** ***Hippopotamidæ, Suidæ, Hyopotamidæ, Xiphodontidæ, Anoplotheridæ, Oreodontidæ.***

DIVISION II. RUMINANTIA, with ***Families: Camelidæ, Tragulidæ, Cervidæ, Camelopardidæ, Antilopidæ, Ovidæ, Bovidæ.***

ORDER TILLODONTIA.—Molars as in Ungulates. Canines. Plantigrade and pentadactyl. Unguiculate? ***Families: Tillotheridæ*** (281), ***Stylinodontidæ.***

ORDER TOXODONTIA.—Allied to Ungulates, Rodents, and Edentates.

ORDER CARNIVORA.

SECTION I. PINNIPEDIA.—Seals and Walruses.

SECTION II. PLANTIGRADA.—Bears. Walking on whole length of foot.

SECTION III. DIGITIGRADA.—Walking on the toes. ***Families: Mustilidæ, Viverridæ, Hyænidæ, Canidæ, Hyænodontidæ, Felidæ.***

ORDER RODENTIA.—Gnawing Mammals. ***Families: Leporidæ, Lagomyidæ, Cavidæ, Hystricidæ, Cercolabidæ, Octodontidæ, Chinchillidæ, Castoridæ, Muridæ, Dipodidæ, Myoxidæ, Sciuridæ.***

ORDER CHEIROPTERA — Bats. *Nyctilestes, Nyctitherium.*

ORDER INSECTIVORA.—***Families: Talpidæ, Soricidæ, Erinaceidæ.***

ORDER QUADRUMANA.—*DIVISION I. STREPSIRHINA* (Prosimiæ).—Lemurs. ***Families: Lemuridæ, Lemuravidæ, Limnotheridæ.***

DIVISION II. PLATYRHINA.—Tailed Monkeys.

DIVISION III. CATARHINA.—Including Anthropoid Monkeys.

§ 2. Nature of the Succession of Organic Forms.

The foregoing tables are a systematic exhibit of the larger types of plants and animals which appeared on the earth in the progress of geological time, and which continue, for the greater part, to dwell in the waters and upon the land, of the modern world. No Class of animals once existing has totally disappeared. Only a very few Orders have become extinct — and these chiefly Vertebrates, dwellers on the land, where the vicissitudes of climate and other conditions have been most directly and most severely felt. Scarcely a marine Order is found extinct. A large majority of the marine Families still survive.

Some further inferences of a fundamental character derived from palæontological studies should be here enunciated.

1. *The Succession of Organic Forms has been a general Progress from lower to higher.* The lowest position in which organic remains have been found is in the Laurentian. We find here mere traces of organisms related apparently to some of the lowest and simplest creatures now living. We shall presently give them a more particular description.

Searching through the overlying Huronian strata, we find no certain evidences of the former existence of life. But immediately on entering the Cambrian strata, such evidences are very abundant, and they never fail through all the higher formations.

Throughout the Cambrian, the fossil remains pertain exclusively to Invertebrates. During the Cambrian were introduced all the leading Clases of Molluscs now known. Also some characteristic Class types of Cœlenterata, Echinodermata and Arthropoda. There are also indications of Vermes. So all the Stems or Subkingdoms of animals now known, except Vertebrates, have been upon the earth from Cambrian times. But the Classes were low; the Orders represented were low in their respective Classes; and the Families were low in the Orders to which they belonged. This is a general law.

Before the close of the Silurian, Fishes existed. These are the lowest Class of Vertebrates; and the Orders represented were low in their Class. They were not well defined and characteristic Fishes. The true Fishes appeared in the Mesozoic Ages. But the Palæozoic fishes, if we call them such, became very abundant and powerful, and constituted what we may style a ruling dynasty until the approach of the Carboniferous Æon. The Silurian and Devonian fauna was thus a great advance on that of the Cambrian.

The time which had now elapsed was enormous beyond computation; but only marine animals had been in existence. Next, in approaching and entering the strata of Carboniferous time, we discover remains of Amphibia. Fishes still existed; but Amphibia were the highest type; and they attained such dimensions, were clad in such armor, and ramified in genera and species so numerous, that they became strictly the dominant type in the animal world. This was the easier because the hugest of the armored fishes had mostly disappeared. These air breathers in adult life were a further advance in the grade of organization on the earth.

Next came the Class type of Reptiles. They expanded enormously during the Mesozoic Æon. The Fishes and Amphibians became subordinate. This was a reign of Reptiles. Toward the close of the Mesozoic, Birds began to appear — first, with long reptilian tails and toothed jaws; then with toothed jaws and shortened tails; then under the typical forms of Birds — *Ratitæ*, Cursores, or Running Birds first, and *Carinatæ*, or Perching and Flying Birds next. So here was further exemplified the principle of progress which had been operative from the beginning.

Next, coming to the study of Tertiary strata, we discover the remains of many Mammals. They had begun already to exist in a feeble way, as far back as the Jurassic Age — probably earlier. But here they became dominant. They were not only the highest in rank; they attained, in many cases, gigantic dimensions, and were provided with formidable means of offence. They were the faunal characteristic of the Tertiary.

Lastly, after all the foregoing histories had en en
man came on the scene. He is the last term of a l

2. *The earlier representatives of Class and Or as*
were generally Comprehensive. The individual ani
characteristic example of its Order or Family, but uni
some characters of other orders and families —
eral orders or families. The associated characters were to be
arated in later time, and organized in an ordinal or ily t
or even a class type, more clearly defined. Thus the ly
retained some of the plated characteristics of Cr o ,
perhaps more important affinities with certain T ates, and
some characteristics which later were to belong to
and Reptiles. Amphibians breathed like I es wh yo
like Reptiles when adult. They were, and l n, a
prehensive type." The Reptiles, when they ived,
with proper reptilian characters, some others which were

—as if inherited from the fishes. The earliest birds, in their teeth and long vertebrated tails, still clung to characteristics of a dynasty passed away, and were also a comprehensive type. The same principle is strikingly exemplified in the whole Tertiary history of the Mammals. It was a law in the succession of life.

Thus, we must not conceive successive types of organization as separated from each other by sharp and fixed lines. They rise into prominence like waves of the sea, blending on their borders with contiguous developments of organization, and then gradually sinking again, to give place to another swell in the ocean of life.

3. *The graduation in the organic succession is not complete, so far as known.* Here we must first announce the fact, and then append a reflection. The "missing links" or "gaps" in the organic succession are facts of importance. Let us enumerate some of them: (1) Between *Eozoön*, the first known animal, and the Cambrian forms, next known. (2) Between Cambrian Invertebrates and Silurian Fishes. (3) Between Fishes and Amphibians. (4) Between Mammals and older Vertebrates. (5) Between Man and lower Mammalia. To these some persons add (6) Between Inorganic Matter and *Eozoön*. (7) Between Unintelligent organization and Intelligence.

Our first knowledge of a type presents it under a somewhat complete development. Our contemplation of the succession of dominant types reveals a series of high wave crests, which give the impression of sharply distinct advents of organic types into existence. Hence the revelation of "gaps" is, at first view, a glaring fact.

But when we consider the facts of palæontological history a little more closely, we discover: (1) Even if the actual graduation were originally complete, we could expect to acquire only a broken knowledge of it, because (*a*) only a small fraction of the earth's surface has been explored for fossils, or ever can be; (*b*) in no locality have the rocks been completely investigated; (*c*) if all the rocks everywhere were completely investigated, we could not expect to discover a complete record of past life, since the greater part of the forms once living have totally perished. Hence, missing links, even if irrecoverable, signify little as a ground for inference. They simply demonstrate gaps in our knowledge. (2) A closer study shows that the supposed gaps are not so wide as imagined. The so called Silurian Fishes reveal graduations downward toward Crustaceans and Tunicates, and upward toward Amphibians. So of all the great salient types. They are all "comprehensive"; and the characteristic of a comprehensive type is to blend to some extent with neighboring types. (3) The daily progress of discovery brings to view types which fit into the existing gaps. The gaps are becoming filled up. There are already long lines of succession where the graduation from lower to higher is as gentle and complete as could be demanded to support an extreme inference. The tenor of progress foreshadows the complete closing up of the gaps. It shows, at least, that they would probably be filled if we could recover the complete record. It seems to be more rational in this day to *anticipate* this result than to attribute high significance to defects in our knowledge which to-morrow may no longer exist. We may, therefore, reason from the chain of organic being, as if no links were missing.

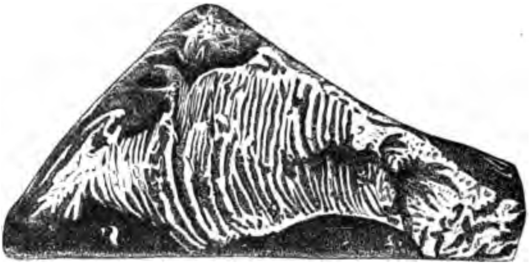


FIG. 220.—WEATHERED SPECIMEN OF *Eozoön Canadense*. From Limestone at Tudor, Ont. (Carpenter.)

§ 3. The Dawn Animal.

We will now glance more particularly at some of the dominant types of organization. In doing this, the student should make frequent reference to the table of classification in the second section of this chapter. First of all was *Eozoön.* The remains of its calcareous skeleton have been found far down in the Laurentian System, in a great bed of crystalline limestone. When exposed on the weathered surface of the rock it appears formed of numerous bent or undulate layers parallel with each other, as shown in Fig. 220. These layers, in most cases, consist alternately of serpentine and calcium carbonate. When a thin cross section is made and highly magnified, we are enabled to detect a minute structure bearing considerable resemblance to certain Foraminifera. We should wander too far to enter into details of explanation, and must be content with stating that *Eozoön* is generally regarded foraminiferal in its affinities.

We may, then, give some account of its structure and mode of life. At the beginning of its growth it consisted of a small mass of gelatinous substance spread on some support in the bottom of the sea. It probably resembled the well known *Amœba* living in modern fresh waters, of which one is represented in Fig. 221. This is a minute speck of gelatinous matter containing *granules*, a *nucleus*, *n*, and a *contractile vesicle*, *c v*. Extensions from the mass of the animal's body, called *pseudopodia*, are capable of complete withdrawal, and fusion in the common mass. Other pseudopodia may be extended at the animal's pleasure. This minute creature, without permanent members, without stomach or other organs, possesses

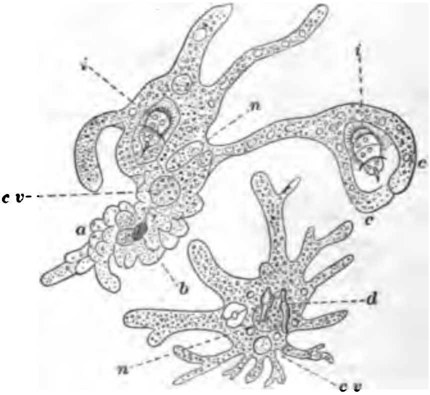


FIG. 221.—*Amœba Proteus*. (After Leidy.) A LIVING REPRESENTATIVE OF THE OLDEST ANIMAL. *n*, nucleus; *c v*, contractile vesicle; *a*, posterior portion in a contracted state; *c*, *c*, two pseudopods closing around an Infusorian (*Urocentrum*); *d*, diatoms within the animal; *b*, particles of sawdust. Magnified 100 diameters in the upper specimen, and 125 in the lower. Found frequently in fresh waters.

all the essentials of animal life. It hungers and feeds; it wills and moves; it is self-conscious and seeks to satisfy its wants. This is nearly the simplest form of organization known. (See page 306.) It stands as a representative of the oldest type of animal existence.

But the first animal found its home in the stormy sea. It must be sheltered from the violence which raged around it. A thin, shelly covering was secreted over it. This was perforated by innumerable minute tubuli, and by some larger pores, and was supported at intervals by calcareous pillars. Over this shell was built a thicker and coarser covering, known as the *supplementary skeleton*. This was perforated by branching *canals*, through which the gelatinous matter found its way to the exterior. Here new pseudopods were extended, and new gelatinous matter was outspread, and a new roof was built, supported, like the first, by numerous stony pillars. This process was repeated again and again, and the mass grew indefinitely. The accompanying diagram is intended to illustrate the mode of growth just described. Organisms of this sort were probably planted in innumerable places along certain favorable tracts of sea bottom. In the progress of their growth many coalesced together, and enormous reef-like masses came, in the course of ages, into existence. Around these the sediments gathered, and all that remained of *Eozoön* was buried thousands of feet in rock-forming mud.

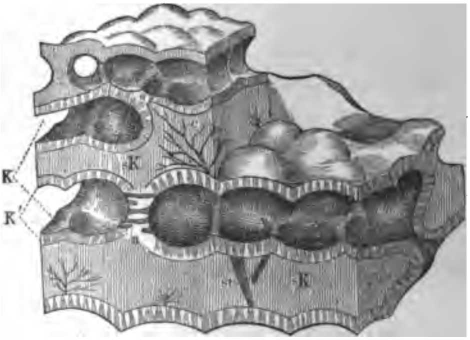


FIG. 222.—DIAGRAM OF STRUCTURE OF *Eozoön*. (Bütschli, after Carpenter.) *K*, Chambers of two successive layers; *a*, Shelly partitions, perforated by passages; *K'*, Proper walls of the chambers, composed of finely tubular shell substance—the "nummuline layer"; *sK*, Intermediate, or supplementary skeleton, traversed by *st*, stolons of communication between two chambers of different layers, and by *c*, a system of canals.

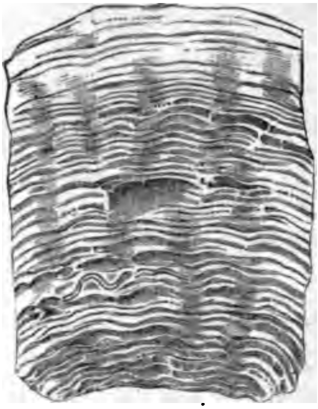


FIG. 223.—*Stromatocerium rugosum.* FROM THE CAMBRIAN OF NEW YORK. (After Hall.)

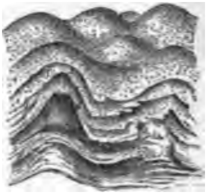


FIG. 224.—VIEW OF A STROMATOPOROID, *Stromatopora tuberculata* (Nicholson). FROM CORNIFEROUS LIMESTONE.

But, though *Eozoön* disappeared from existence, the type to which it belonged survived. In the Cambrian we have long known a form represented in Fig. 223, and called *Stromatocerium rugosum.* This, in external aspect, resembles *Eozoön*, but its zoölogical affinities remain somewhat in question.

It will be interesting to trace the last named type a little further. It is the type of the *Stromatoporidæ.* In Fig. 224 is a view of another Stromatoporoid. The typical *Stromatopora*, when cut through, is seen to consist (Fig. 225) of a large number of concentric laminæ, separated by very thin intervals, and connected by innumerable pillars passing from lamina to lamina. This is a simple *Stromatopora.* Sometimes the pillars become more or less obscure (Fig. 226); sometimes they disappear; sometimes the laminæ are all raised at intervals into little eminences, shown in Figs. 224 and 227; sometimes small, radial, sinuous, and branching canals diverge from one or more perforations in these eminences (Fig. 227); and by these and similar variations, we find established a number of generic distinctions. *Stromatocerium* is a genus without pillars, and having all the laminæ pierced by small holes. Three genera, *Stromatopora*, *Cœnostroma*, and *Idiostroma*, are extremely abundant in the Devonian limestone of Little Traverse Bay, Michigan. The first is small, from the size of a hickory nut to that of one's fist. The second grows in huge dome-shaped masses, some of which have been measured over twelve feet across, and recall the reef-like bulk of long extinct *Eozoön*. The third genus is an enormous tangled mass of branching stems, each a third of an inch in diameter, and having a true stromatoporoid structure. Stromatoporoids are widely distributed through the Devonian, and they are also common in the Silurian. Their nearest affinities are yet undecided. They have by different authorities been referred to the Foraminifera, the Sponges, the Anthozoa, the Hydrozoa, and the Polyzoa. Probably they must be considered one of the comprehensive types (described on page 316), which cannot be assigned precisely to any recognized position.

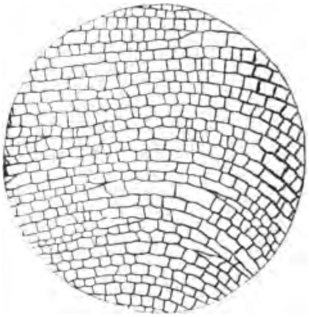


FIG. 225.—INTERNAL STRUCTURE OF *Stromatopora striatella* D'ORB. × 7. (From Nature.)

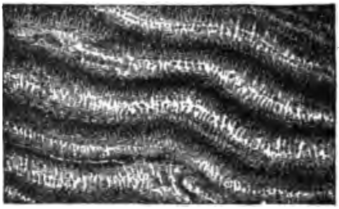


FIG. 226. VERTICAL SECTION THROUGH *Cœnostroma monticuliferum*. (From Nature.) SHOWING OBSCURE LAMINÆ AND PILLARS.

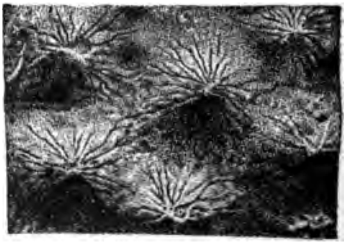


FIG. 227.—EXTERIOR OF *Cœnostroma monticuliferum*. × 2. (From Nature.) SHOWING MONTICULES AND RADIAL CANALS.

The type of Foraminifera, of which *Eozoön* and the Stromatoporoids combined some of the characteristic features, became, in later times, completely eliminated, and underwent, during Mesozoic and Cænozoic times, a remarkable diversification. It survives to-day in a large number of representatives.

Eozoön played the first role in the drama of life. It was the great lime-secreting and reef-building agent of the early ages of the world. Later, this function was assumed by organisms of another and higher class.

§ 4. Trilobites.

At the very opening of the Cambrian Age, Trilobites were present. Their advent and reign form a striking feature in the history of life. Some of their forms are shown in Figs. 228–230. They were Arthropoda, holding a position low in the Class Crustacea. The body was distinctly trilobed. The anterior portion constituted a *cephalic shield*, usually bearing a pair of sessile compound eyes, with a raised, often lobed (Fig. 229) central part, known as *glabella*.* The number of thoracic segments was very variable. The abdominal segments were firmly united, and formed a caudal shield. Fig. 231 is a diagram showing the principal parts of a Trilobite, as seen from above.

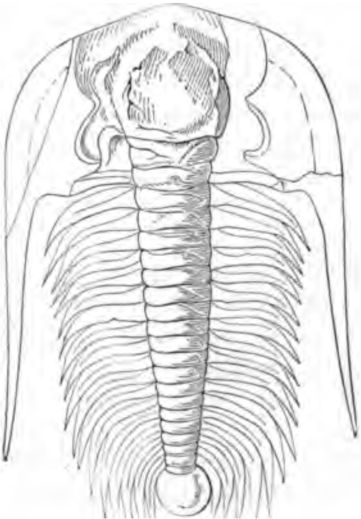


FIG. 228.—*Paradoxides Harlani*. (After Walcott.) FROM EARLY CAMBRIAN.

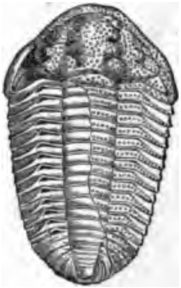


FIG. 229.— *Calymene Blumenbachii*, VAR. *Niagarensis*. FROM NIAGARA GROUP.

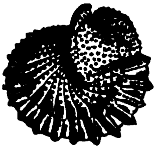
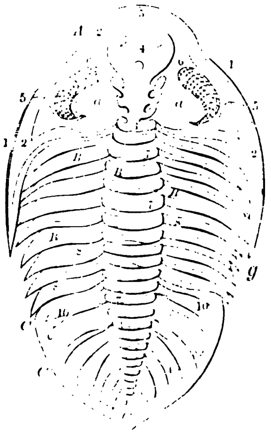


FIG. 230.—SAME AS LAST, ROLLED TOGETHER.



Some of the lowest Cambrian strata are crowded with the fragments of these articulates. They continued abundant during the Silurian; diminished during the Devonian, and became extinct during the Carboniferous. Their nearest living representative is the King Crab (*Limulus*) of our eastern coast, the embryo of which presents a strikingly trilobitic aspect.

FIG. 231.—DIAGRAM OF THE STRUCTURE OF A TRILOBITE.

A, HEAD. 1, External Border of the Limb. 2, Marginal Furrow. 3, Occipital Ring. 4, Glabella. 5, Great Suture, passing in front of the Glabella, and inside of the Eyes. 6, Eyes and Subocular Suture. *a*, Fixed Cheek, forming along side of the Eye, the Palpebral Lobe, *a* 5. *b*, Movable Cheek. *g*, Genal Point.

B, THORAX. 7. Ring of the Axis of each Segment of the Thorax. 8. Rib of each Segment of the Thorax.

C. PYGIDIUM. 9. Continuation of the Axis. 10, Continuation of the Ribs.

§ 5. Crinoids.

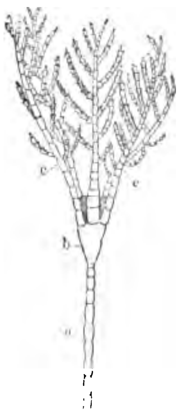


FIG. 232.—*Rhizocrinus Lofotensis.* (After W. Thomson.) A LIVING CRINOID. × 2.

A crinoid consists of *body* and *arms*, supported on a *stem*, which is generally rooted in the submarine soil. It presents the appearance of a tree, and hence is embraced in the group formerly known as *zoöphytes* (Fig. 232). The parts mentioned are composed of calcium carbonate, and each consists of a number of pieces nicely fitted together. The stem is a pile of circular or pentagonal discs, with a central canal extending the whole length. The *calyx*, or *cup*, consists of regularly shaped plates fitted by their edges. The arms, five in number, are ranges of discoid, or imperfectly cylindrical pieces, in one or two series, joined by their flattened surfaces, but not, like the stem, perforated for a canal. The arms generally bifurcate near the base, and afterward again. From one or both sides of each arm generally spring pinnulæ, constructed like the arms, but smaller. Over the calyx, in the extinct species, is generally built, of nicely fitting plates, a dome bearing the passages to and from the interior. Sometimes one of these opens at the apex of a proboscis which rises from the dome. The plates of the calyx are often elegantly furrowed or sculptured. Their forms, number and arrangement are shown in Fig. 233, which represents the plates of a calyx spread out horizontally. They are grouped as *Basal*, *Radial*, *Interradial*, and *Azygos* plates. The basal, b, b, b, consist generally of a cycle of three plates resting on the top of the stem. Frequently, however, there are two cycles of basals. Whether of one or two cycles, the basals are surmounted by five series of radials, r. Each series consists of the *primary*, *secondary*, and (sometimes) *ternary*, *radials* (r^1, r^2, r^3). Between the radials are *interradials* (i^1, i^2, i^3), which generally exist in two or more cycles, having a definite number between each two series of radials, except on one side, called the *azygos interradius*, where the number is much greater (a^1, a^2, etc.). It will be seen that the principle of bilaterality is fully exemplified in this arrangement. A line drawn from the azygos side through the centre of the opposite radial series divides the structure into right and left parts, perfectly symmetrical with each other.

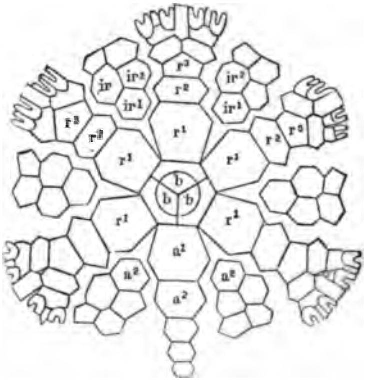


FIG. 233.—CALYX OF A CRINOID, SPREAD OUT TO SHOW THE FORMS, NUMBER, AND ARRANGEMENT OF THE PLATES. b, b, b, Basal Plates. r^1, r^2, r^3, Radials. $i\ r$, Interradials. a^1, a^2, Azygos Interradials. There are here three radials in each radius; four interradii, each with five interradials, and one azygos interradius, with a larger number of pieces.

These elaborately constituted organisms were in existence in the Cambrian Age. The type underwent expansion in number and elaborateness through the Silurian, continued through the

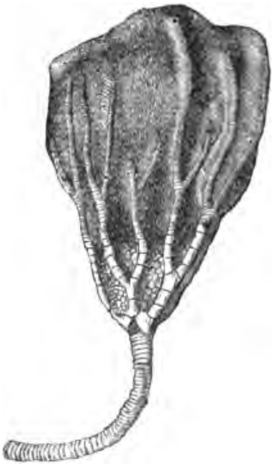


FIG. 234.—A CARBONIFEROUS CRINOID, *Forbesiocrinus communis*, WAVERLY GROUP, OHIO.

Devonian, and attained its greatest development in the Lower Carboniferous. Certain genera lived through the Mesozoic; but the type at the beginning of the Tertiary was nearly extinct. Till recently, but one living species was known. Now, however, a number of additional species have been dredged, mostly from the Gulf Stream, off the coasts of Florida and Scandinavia, the late Challenger Report enumerating six genera and thirty-two species. It is a very remarkable circumstance that among the genera represented is ***Rhizoc'rinus***, Fig. 232, which began its existence in the Cambrian Age. In the cold depths of the ocean, changes of conditions are slight, and slow. We judge that the modern conditions have persisted substantially from the dawn of crinoidal life.

§ 6. Chambered Shells.

Another of the conspicuous types of organization of which the elementary student should have some knowledge is that of Tetrabran'chiate Ceph'alopods. These molluscs secreted an external calcareous shell, in form a hollow, tapering cone, straight or bent, and divided at intervals by transverse partitions called *septa*. The intervening spaces are *chambers*, and the last one is occupied by the animal, as shown in cut, Fig. 235. The animal—to judge from the *Nautilus*, the only living genus—was furnished with many flexible prehensile *tentacles*, or *arms*, well developed eyes, a pair of horny *mandibles*, two pairs of plume-like gills, a *funnel*, for expulsion of respired water, and a ***siphuncle***, consisting of a membranous or calcareous tube, which reached from the posterior part of the body through all the septa and chambers. The siphuncle, in some families, passed through the centre of the shell, or near it; in others it was closely *marginal* on one side or the other (*dorsal* or *ventral*). See the upper row of outlines in Fig. 236.

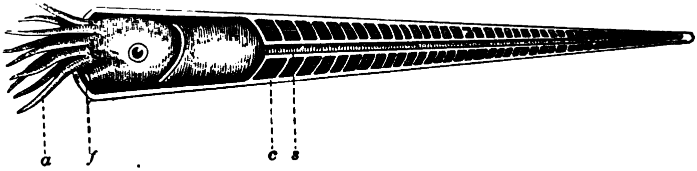


FIG. 235.—RESTORATION OF AN *Orthoceras*—A STRAIGHT, CHAMBERED SHELL OF PALÆOZOIC TIME. *a*, arms; *f*, funnel; *c*, chamber; *s*, siphuncle.

The septum was sometimes simply concave, as at *e;* and in this case the siphuncle was central, or sub-central. Sometimes the *suture*, or line of junction with the shell, was broadly undulate, and the siphuncle was on the *inner* side, as at *d.* Sometimes, with siphuncle close to the *outer* margin, the suture was simply *lobed* (curved or angulate), as at *c ;* or, with the lobe *denticulated*, as at *b ;* or, with the lobes *lobulate* and denticulate (often called *foliated*), as at *a*.

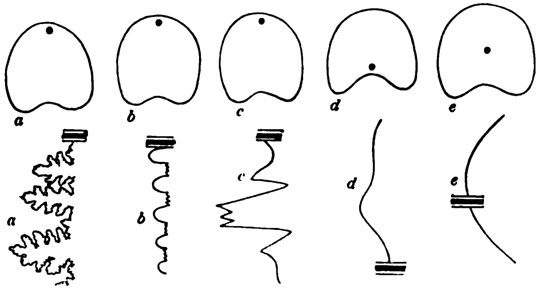


FIG. 236.—POSITION OF SIPHUNCLE AND FORM OF SEPTA IN VARIOUS TETRABRANCHIATE CEPHALOPODS. The upper row of figures represents transverse sections of the shells; the lower row the edges of the septa. *a*, *a*, *Ammonites ; b*, *b*, *Ceratites ; c*, *c*, *Goniatites ; d*, *d*. *Clymenia ; e*, *e*, *Nautilus*, or *Orthoceras*.

The five different styles represent degrees of complication. According, therefore, to the method of nature (page 315), the simplest styles are the more ancient, and began to exist in the

Cambrian. In the Cambian and Silurian the type underwent its greatest development, though it still survives in *Nautilus*. The angulated septum belongs to the Devonian; the lobed septum, to the Carboniferous, though it began in the Devonian; the denticulate-lobed septum characterizes the Triassic, and the foliated septum is known only in the middle and later Mesozoic.

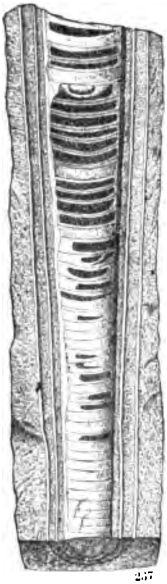
Again, these chambered shells exhibit all degrees of enrolment, from straight to closely coiled. These variations may be advantageously set forth by means of the scheme on the following page. Here we have, first, an analysis of the form, and opposite this, in two columns, the names of genera possessing the several forms. In the first column are generic names of *Nautiloidea*, and in the next names of *Ammonoidea*. The names of Nautiloidea which stand a little indented are of the type having a contracted *aperture;* and the names of Ammonoidea which stand a little indented are of the *Ceratites* type, having the lobes denticulated. We witness in this table an interesting exemplification of nature's tendency to permutation of characters, or repetitions of characters of second order under each of the characters of first order.

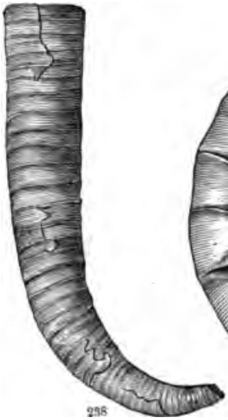
The Tetrabranchs are divided into *Nautiloidea* and *A*
noidea, the former having the suture simple and the siphun
central or sub-central; and the latter having the suture lo
foliated, and the siphuncle mostly close on the ven
margin. Of the Nautiloidea the three most impo
are the *Orthocerat'idæ,* having the shell straight (I
the *Cyrtoceratidæ,* having the rapidly tapering
bent (Fig. 238), and the *Nautilidæ,* having the shell coile
a plane (Fig. 239). The *Orthoceratidæ* underwent an e
dinary development during the Cambrian and Silurian —
times attaining a length of fifteen feet — and were
during the Devonian. During all the Carbonifero
on the wane, and are not known later, except as a
ment in the Trias. The *Nautilidæ* appeared at the
of the Silurian, became plentiful in the Carbonif
genus *Nautilus* still survives.

FORMS OF CHAMBERED SHELLS.

					Nautiloid'ea.	Ammonoid'ea.
Straight				not reflected	Orthoc'eras. Gomphoc'eras.	Baculi'tes. Rhabdoc'eras.
				reflected		Hamuli'na.
Arcuate					Ascoc'eras. Glossoc'eras.	Ptychoc'eras.
Half Coiled					Cyrtoc'eras. Phragmoc'eras.	Toxoc'eras.
Coiled	discoidally	loosely	not produced		Gyroc'eras.	Picte'tia. Choristoc'eras.
			produced	not reflected		Crioc'eras.
				reflected		Ancyloc'eras.
		closely	not produced	umbilicate	Nautilus. Hercoc'eras.	Ammoni'tes (Arietites) Cerati'tes.
				involute	Nautilus (Bisiphi'tes).	Ammoni'tes (Shæroc'eras)
			produced	not reflected	Litui'tes. Ophidioc'eras.	Scaphites.
				reflected		Macroscaphi'tes.
	helically	loosely			Trochoc'eras. Adelphoc'eras.	Heteroc'eras, Helioc'eras.
		closely				Turrili'tes. Cochloc'eras.

The Ammonoidea were mostly Mesozoic, and underwent a remarkable development in respect to diversification and numbers. The *Clymenidæ*, with internal (dorsal) siphuncle and angulated suture lines, were restricted to the Devonian, and never became numerous. The *Goniatitidæ* were more important. They had a closely ventral (external) siphuncle, and a suture line bent into *lobes* and *saddles* (forward pointing and backward pointing lobes). They made their advent in the Devonian and became an important type in the Carboniferous. Since the Palæozoic they have been extinct.





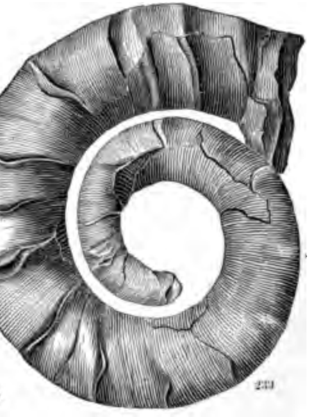


Fig. 237.—*Orthoc'eras Carleyi*, Devonian, Ohio.
Fig. 238.—*Cyrtoc'eras Eugenium*, Corniferous, New York.
Fig. 239.—*Gyroc'eras undula'tum*. Corniferous, Cherry Valley, N. Y.

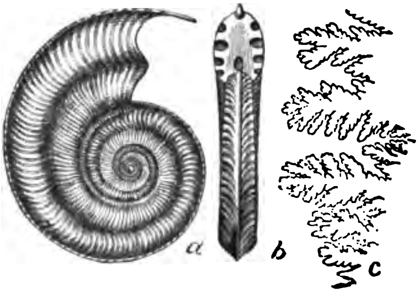


Fig. 240.—*Ammoni'tes serpenti'nus*. *a*, side view; *b*, edgewise view; *c*, plan of suture-lobes.

§ 7. Fishes.

The earliest vertebrates were fish-like, and we commonly group them with Fishes; but probably, if their characters were completely known, we should feel constrained to establish one or more separate classes for their reception. TELEOSTEI, or ordinary fishes, have the skeleton completely ossified; but sturgeons and sharks have an imperfectly ossified skeleton. The earliest fishes appear to be somewhat allied to these, and they are commonly arranged under two orders: GANOIDEI, having the *exoskeleton* (or bony developments of the surface) in the *ganoid* scales, plates or spines, and ELASMOBRANCHII, including *Sharks*, *Rays*, and *Chimæræ*, having the exoskeleton *placoid*—consisting of grains or tubercles. The Ganoidei are subdivided into *Lepidoganoids* (scale-covered) and *Placoganoids* (plate-bearing). The last embrace the Sturgeons, which are modern, and the *Placoderms*, which are one of the oldest types of fishes. Until lately the oldest known American fishes were Devonian, though a Silurian fish-bed has long been known in England. In 1884, however, Professor Claypole announced the discovery of American fishes in the middle Silurian of Pennsylvania; that is, as low as the bottom of the Salina Group; while the oldest European fishes are supposed to be of the age of the Helderberg Group. The name of the oldest fish known is *Palæas'pis*, "ancient shield." Indications, however, are found of still older fishes in the Clinton sub-group, and named *On'chus Clintoni*. This group probably corresponds to the Upper Llandovery of England.

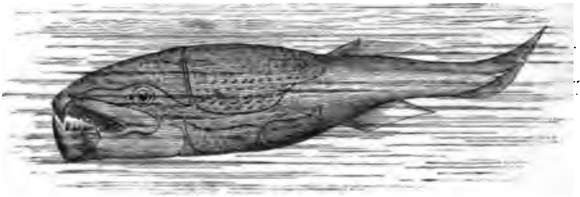


FIG. 241.—RESTORATION OF *Dinich'thys Herz'eri*, A PLATED GANOID FROM OHIO. (Newberry).

The oldest well preserved Placoderms in America come from the Devonian Huron Shale of Ohio, and have been described by Dr. Newberry. One of these is named *Dinich'thys*, or "terrible fish." *D. Herzeri* appears to have attained a length of at least twenty feet. Its head was three feet long and two broad, and the under jaws were two feet long. A restoration of this species is shown in Fig. 241. The tail, it will be noticed, like that of most Palæozoic fishes, was *heterocercal*, or "unequal-lobed." In the Devonian flourished also huge Lepidoganoids. One of the Ohio species is named *Onych'odus sigmoi'des* by Newberry. The skeleton was cartilaginous, but the teeth were long and formidable. A group of these is shown in Fig. 242. It had jaws twelve to eighteen inches long, and probably attained a length of twelve to fifteen feet. Besides Ganoids, th[illegible] w[illegible] huge Elasmobranchs of the [illegible] b[illegible] ag'iostomes, which includes [illegible] Rays, and the type of [illegible] Sharks, some of which [illegible]ll live [illegible] lian seas. The back teeth in the latter [illegible] obtuse, and there was a p[illegible] ul [illegible] front of each dorsal fin. F[illegible] 3 [illegible] of these spines from New Y[illegible] when perfect, was as least ten inches long. The [illegible]

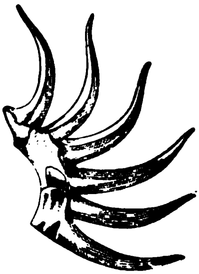


FIG 242.—GROUP OF FRONT TEETH OF *Onych'odus sigmoides*, A SCALED GANOID FROM THE CORNIFEROUS OF OHIO. (Newberry.)

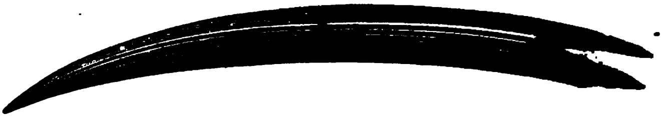


FIG. 243.—SPINE OF AN EXTINCT CESTRACIONT SHARK. *Machæracan'ti* [illegible] Hall.)

and still another group, Hyb'odonts, more [illegible] Sharks, became abundant during the Mes[illegible].

In Europe, the *Pterich'thys* or "W[illegible] has been long a familiar form. This [illegible] a co[illegible] *alas'pis*, "Shield Head" and *Cocos'teus*, "Berry Bone," and several others.

From Canada, at Scammenac Bay, Mr. Whiteaves described a *Pterich'thys Canadensis*, Fig. 247. It has, however, no tail, and the sculpturing of the plates resembles *Bothriol'epis*, of which species are known in Europe, and in the Catskill Group of America. Cope points out some remarkable affinities with an Arctic Tunicate, Fig. 248, and infers that the *Pterichthy'idæ* are not a distant remove from an ancestral type of Tunicates. From the same locality are described other fish remains, among them a *Phaneropleuron*, a near relative of the living Queensland *Cerat'odus*, and species of the genera *Diplacan'thus*, *Acantho'des*, *Eusthenop'teron*, *Glyptol'epis*, *Cheirol'epis*, *Coccos'teus*, *Cephalas'pis*, *Ctenacan'thus*, and *Homacan'thus*.

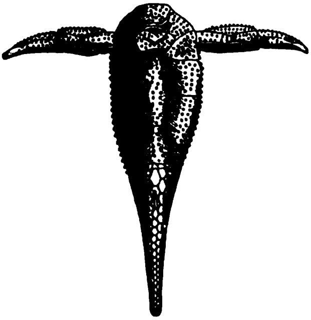


Fig. 244.—*Pterichthys Milleri*, from the Devonian of Scotland. (After Pander.)

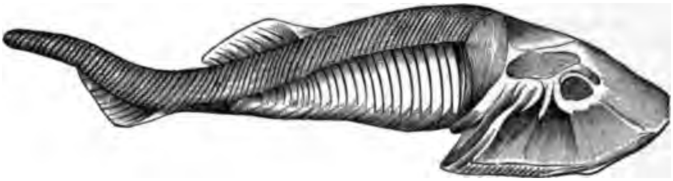


Fig. 245.—*Cephalas'pis Lyelli*. (After Brown.)

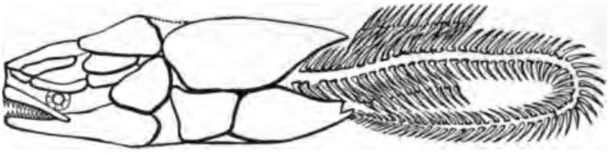


Fig. 246.—*Coccos'teus decip'iens*. (After Jukes.)

The types to which these Placoderms and Cestracionts belonged passed mostly out of existence during Palæozoic time. The Lepidoganoids and ordinary Sharks continued to flourish during the Carboniferous and the Mesozoic. Teleost Fishes began to appear in the Jurassic, but only became abundant in the Cretaceous and later ages. They remain the dominant type of fishes to-day, though a slender representation of some of the older types still survives. The common gar pike, *Lepidosteus*, is well known in our western and southern fresh waters. It has acquired, however, a bony skeleton, and the tail is less heterocereal than that of the allied ancient species.

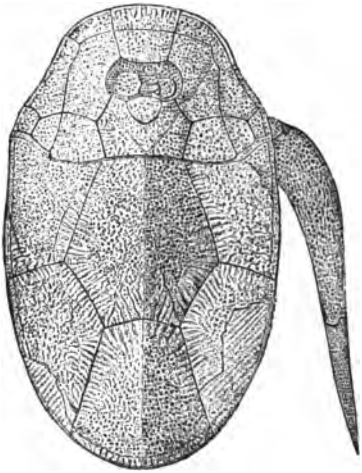


FIG. 247.—*Bothriolepis Canadensis*, Whiteaves sp. VIEWED FROM ABOVE. HALF SIZE OF A SMALL SPECIMEN (Cope). FROM THE UPPER DEVONIAN.

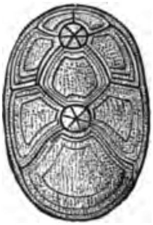
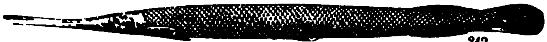


FIG. 248.—*Chelyoso'ma Maclovia'num*, Brod & Low. A PLATE-COVERED TUNICATE FROM POINT BARROW, ALASKA. TO ILLUSTRATE AFFINITY WITH *Pterichthyidæ*.



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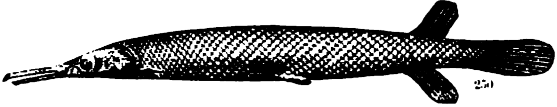

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FIG. 249. *Lepidosteus Huronesis*. THE LAKE GAR PIKE. LIVING IN THE GREAT LAKES. (From Nature.)

FIG. 250. - *Lepidosteus oculatus*, THE SPOTTED GAR PIKE. LIVING IN LAKE ERIE AND SOME SMALL LAKES OF MICHIGAN. (From Nature.)

It will be remarked that the ancient types of fishes possessed in some respects, an *embryonic character*. Their skeletons were cartilaginous like those of the embryos of Teleosts, and their tails are heterocercal or even vertebrated. The tendency of the embryo tail to a vertebrate structure and hence to a heterocercal character may be well seen in the embryo of *Lepidosteus*, a representation of which is given in Fig. 251. This correspondence between embryos of modern types and the adults of ancient types is a general principle in the history of life.

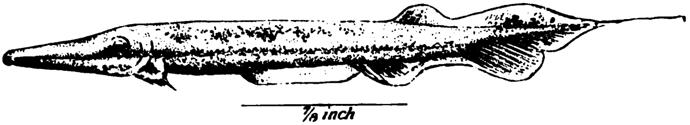


FIG. 251.—EMBRYO OF *Lepidosteus* FROM THE CUMBERLAND RIVER, NASHVILLE, TENNESSEE, SHOWING A VERTEBRATE TAIL. (From Nature.)

To the period of the Coal Measures, Fishes were the highest type of animals in existence. As in the early history of other types, they were also numerous and bulky. For these reasons palæontologists have designated the Devonian and Carboniferous the " Reign of Fishes."

§ 8. **Reptiles.**

Reptiles are essentially a post-Palæozoic type. *Telerpeton* and *Stagonolepis* have been reported from the Elgin sandstones of Scotland, and these have been regarded as Devonian, but they may with great probability be referred to the Trias. It is thought also that *Eosaurus Acadiensis*, a vertebra of which was found by Marsh in the Nova Scotia Coal Measures, may have been a "marine saurian." Generally the place of Reptiles was taken in the Coal Measures by Labyrinthodonts, an Order of Amphibians. Possibly, however, the little *Hylonomus* was a true reptile. In the Permian, the last group of Palæozoic strata, occur in Europe the remains of *Protorosaurus*, a lizard-like reptile, together with other forms.

But the Mesozoic was the theatre of the chief development of Reptiles. Not only were they numerous and often gigantic in dimensions, but many were heavily armored; and the type, while its forms were comprehensive, became wonderfully differentiated, so that reptilian life became fitted to inhabit all elements, and utilize all conditions of existence.

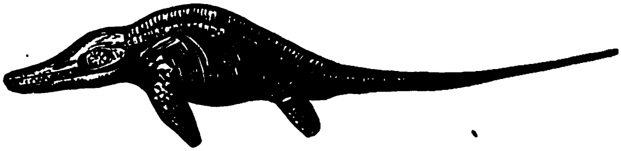


FIG. 252.—*Ichthyosaurus communis.* (D'Orbigny.)

The sea had its reptilian denizens—*Ichthyosauria*, fish-like in their home, their form, their structure. The head of the common *Ichthyosaurus*, Fig. 252, was enormous, with a huge snout; neck wanting; teeth conical, strong, and numerous; orbits of immense size; a long series of ribs extending from the neck to the elongate tail; sternum and sacrum wanting; vertebræ bi-concave; all the limbs paddle-like, composed each of numerous short polygonal bones arranged generally in five longitudinal rows, with a supernumerary row of ossicles on each side, giving the appearance of seven digits, each with many phalanges. Species of *Ichthyosaurus* range through the Jurassic and Cretaceous of the Old World.

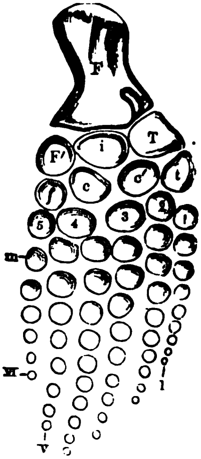


FIG. 253.—LEFT HIND FOOT OF *Baptanodon discus*, SEEN FROM BELOW. × 1-10. *F*, femur; *F′*, fibula; *i*, intermedium; *c*, central bone; *f*, fibulare; *m*, metatarsals; *T*, tibia; *t*, tibiale. Roman numerals indicate the digits in order. (Marsh.)

In America are found the remains of great reptiles related to Ichthyosaurus, but *without teeth.* They attained a length of eight or nine feet. The genus *Baptan'odon*, "toothless bather," and the Order BAPTANODON'TA have been established for them by Marsh. Fig. 253 illustrates the foot of *Baptanodon discus.* Here were six digits.

The student will notice particularly the primitive or low condition of the limbs of these Ichthyosauroids. Each limb was a simple fin or paddle;

the fore and hind limbs were identical in structure; three bones in the second segment of the limb (as *tibia*, *fibula*, and *intermedium*, in the hind limb); the mesopodial bones (carpals or tarsals) simple circular or angularly rounded discs; the number of digits six or more; the metapodial bones (metacarpals and metatarsals) and also the phalanges, mere circular discs, and the phalanges very numerous. These limb-characters, like the general features of *Ichthyosaurus* before enumerated, point clearly to a close relationship with preëxisting and contemporary fishes. The thoughtful biologist cannot avoid the question how such affinities came into existence.

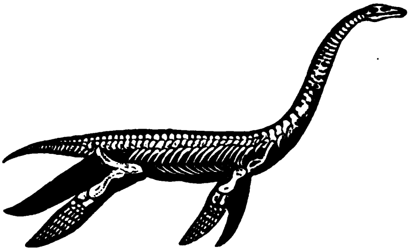
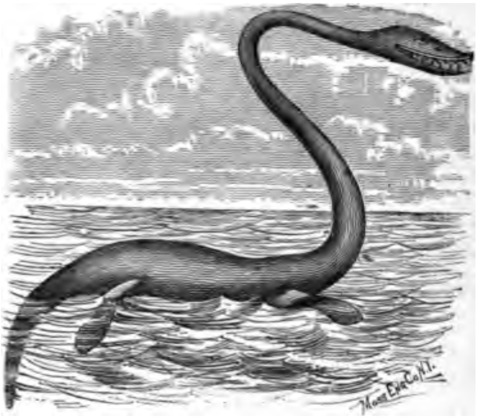


FIG. 254.—*Plesiosaurus dolichodei'rus*. (D'Orbigny.)

The PLESIOSAURIA were other sea monsters. The *Plesiosaur'us* resembled the *Ichthyosaurus*, but differed remarkably in its long neck and snake-like head. A sacrum of two vertebræ was present, and supernumerary digits were wanting. It attained a length of 18 to 20 feet, and ranged through the Jurassic and Cretaceous. *Elasmosaurus platyurus* of Cope attained a length of 50 feet (Fig. 255). Other marine saurians belong to the order PYTHONOMOR'PHA, "sea serpents," of which over forty American


Moss Eng Co N.Y.
FIG. 255.—*Elasmosaurus platyu'rus*. (Cope.)

Cretaceous species are known — fifteen in New Jersey, six or more in the Gulf States, and over twenty in western Kansas. *Mosasaurus princeps*, Marsh, was 75 to 80 feet in length. The body was covered with overlapping bony plates. Each of the four paddles had five digits, but with supernumerary phalanges, like whales. Besides conical saurian teeth in the jaws, there were two rows of formidable teeth along the roof of the mouth, adapted, as in snakes, for seizing their prey. To give lateral motion to the jaws, an exceptional joint existed in front of the usual articulation, and, as in serpents, the two branches of the lower jaw were unconsolidated in front. The structures for swallowing presented, therefore, a truly snake-like aspect. Our modern snakes appear to be dwarfed representatives of the ancient Mosasaurs, still retaining much of their ancient fondness for the water.

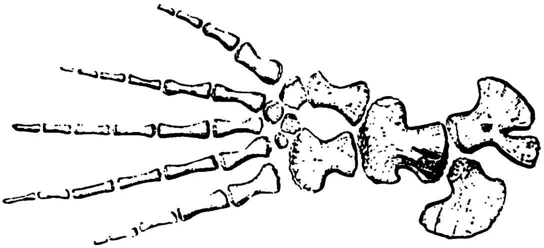


FIG. 256.—RIGHT PADDLE OF *Lestosaurus Micromus*. × 1-12.

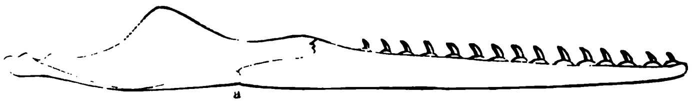


FIG. 257.—RESTORED JAW OF *Edestosaurus dispar*. × 1-6.

The land also had its reptilian denizens. Of these, the DINOSAURIA are by far the most interesting. Though commonly regarded as an Order, the number of modifications of the type has been found so great and so extreme that Marsh proposes to regard the group as a Sub-Class. In one of the Orders, SAUROP'ODA (Lizard-footed), the Jurassic *Atlantosaurus immanis* attained the remarkable length of one hundred feet. The femur was over eight feet long. Its remains occur in Colorado. The related *Morosaurus grandis* was 40 feet long. *Apatosaurus Ajax* had the vertebræ of the neck four feet broad, with a sacrum of three united vertebræ. In another Order, ORNITHOP′ODA (Bird-footed), with only three toes behind, the structure was strikingly bird-like. Among these, *Laosaurus altus* was about ten feet long, and *Nanosaurus* was quite diminutive. In the Cretaceous beds of New Jersey are found the remains of *Hadrosaurus Foulki*, a representative of another family of the bird-footed saurians. This is believed to have been capable of locomotion on its hind feet, or, at least, to have frequently supported itself on two feet while reaching with its fore feet to gather its vegetable diet from the foliage of the forest. Three-toed footprints of some bipedal animals imprinted on the sandstones of the Connecticut valley are, with much probability,

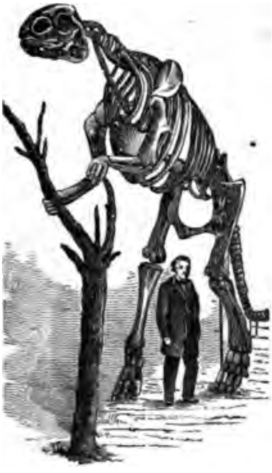


FIG. 258.—*Hadrosaurus Foulki*, A BIPEDAL REPTILE FROM THE CRETACEOUS. (After Hawkins' Restoration.)

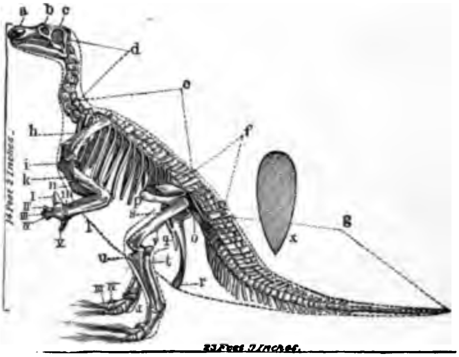


FIG. 259.—*Iguanodon Bernissarten′sis*, BOULANGER, AS MOUNTED IN THE MUSEUM AT BRUSSELS BY DE PAUW. *Head*, *a*, nostril; *b*, orbit; *c*, temporal fossa. *Vertebral column*, *d*, cervical region; *e*, dorso-lumbar region; *f*, sacral region; *g*, caudal region; *h*, scapula; *i*, coracoid; *k*, humerus; *l*, ulna; *m*, radius; *n*, sternum; *o*, ilium; *p*, pubis; *q*, post-pubis; *r*, ischium; *s*, femur; *t*, tibia; *u*, fibula; *v*, third (fourth) trochanter; I, II, III, IV, V, digits; X, diagrammatic transverse section of the body between the fore and hind limbs.

ascribed to some reptile allied to *Hadrosaurus*. *Ornithotarsus immanis* of Cope, from the shore of Raritan Bay, was a colossal Dinosaur, whose hind limb, according to Cope, could not have been less than 13 feet in length.

In the Old World, the Ornithopoda were extensively represented by species of *Iguanodon*. A bed of their remains has recently been brought to light at Bernissart, in Belgium, and the settled conclusion of M. Dollo is that *Iguan'odon* was to some extent *a bipedal walker*. Fig. 259 represents *I. Bernissartensis* as recently mounted at Brussels. The head is 14 feet above

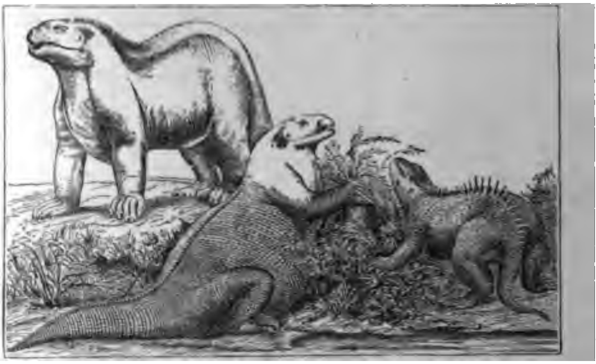


FIG. 260.—REPTILES OF MESOZOIC TIME. The upper and middle figures are after Hawkins. The right hand figure is *Hylæosaurus*.

the floor, and the floor space covered is 23 f
whole length of the animal being over 28 feet.
was an inhabitant of fresh-water marshes, and fed
ferns. It was a powerful swimmer, and th
tions that the toes were webbed. Some
of Iguanodon was made by Hawkins, under t
of London, and Fig. 260 gives the conception of
extant. But it obviously requires some difi

Other, and more characteristically
the Order THERIODONTA, or "Beast-to
Triassic of South Africa. Three sorts of teeth

conical incisors, long, powerful canines, compressed laterally, and minutely serrated behind, together with conical molars (Figs. 261 and 262). In the same bed occur representatives of another order, ANOMODONTIA, or *Dicynodontia*, "Dog-toothed," in which the jaws are converted into toothless beaks (Fig. 263). In some, however, there was a pair of teeth implanted in the upper jaw, growing from *persistent pulps*, and assuming the character of great tusks (Fig. 264.)

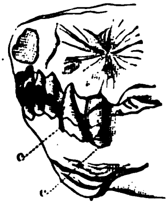


FIG. 261.—JAWS OF *Lycosaurus*. SIDE VIEW. (Owen.) *c*, *c*. Canines.

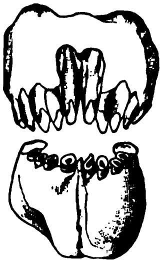


FIG. 262.—JAWS OF *Cynodraco serridens*. FRONT VIEW. (Owen.)

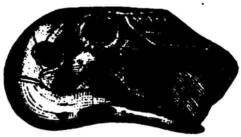


FIG. 263.—*Oudenodon Bainii*. (Owen.)

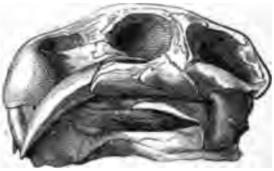


FIG. 264.—*Dicynodon lacertipes*. (Owen.) SHOWING THE MAXILLARY TUSK. TRIAS OF SOUTH AFRICA.

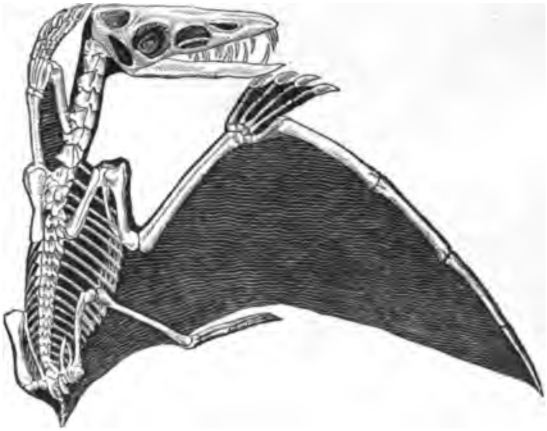


FIG. 265.—*Pterodactylus crassirostris*. FROM LITHOGRAPHIC SLATES OF SOLENHOFEN. (D'Orbigny.) Erroneously represented with five anterior digits instead of four. × $\frac{1}{2}$.

The air, finally, had its reptilian denizens, PTEROSAURIA, "Flying Saurians," having essentially the structural characters of a reptile, but with some bird-like modifications, and a pair of leathery wings stretched from the greatly elongated outer digit, along the side of the body to the tail. We find five modifications of Flying Saurians, all European but one: (1) *Pterodactylus*, having the jaws toothed to the tip, and tail short, Fig. 265; (2) *Dimorphodon* (Fig. 266), with jaws toothed, the anterior teeth largest, and tail very long; (3) *Rhamphorhynchus*, with tips of jaws edentulous, and tail very long; (4) *Pteranodon*, with jaws toothless and tail short and slender—

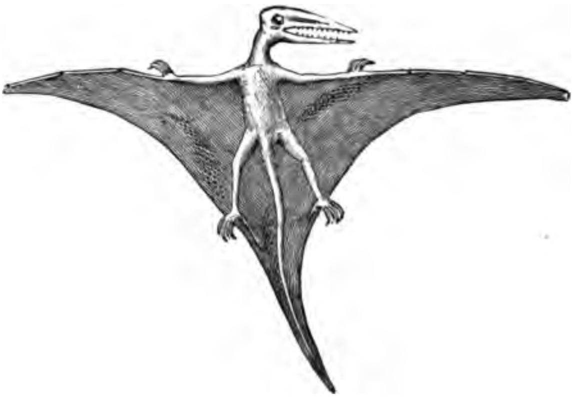


FIG. 266.—*Dimorphodon macronyx*. (After Owen.)

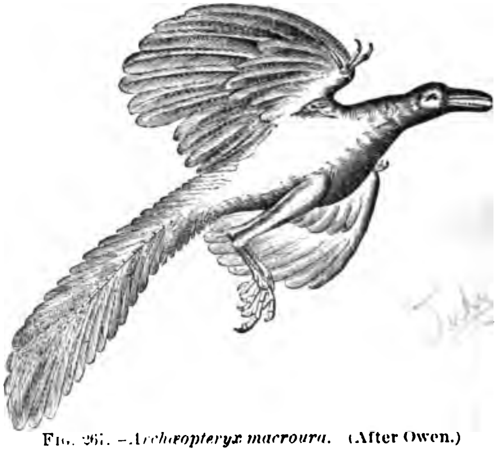


FIG. 267.—*Archæopteryx macroura*. (After Owen.)

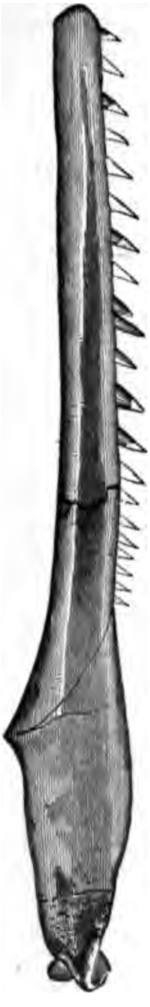


FIG. 268.—LEFT LOWER JAW OF *Ichthyornis dispar*. × 2.

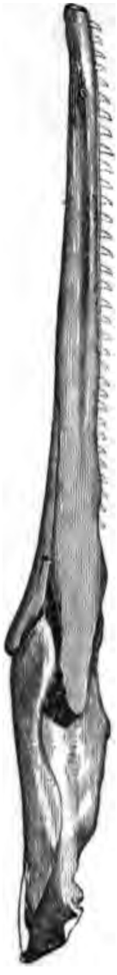


FIG. 269.—LEFT LOWER JAW OF *Hesperornis regalis*. × ½.

comprising gigantic forms from the Cretaceous of North America, some having a spread of 23 feet; (5) *Ornithopterus*, with a wing-finger having only two phalanges.

If to the reptilian forms mentioned we add the other Permian and Mesozoic forms known — true Lizards, Crocodilians, Stegosaurians (plated lizards), and other genera of savage Theropods (beast-footed), like *Megalosaurus*, and *Lælaps*, and other reptiles with hollow bones, the CŒLURIA of Marsh — we may easily believe that the "Age of Reptiles" was one of marvellous luxuriance and diversification of the reptilian type.

§ 9. Toothed Birds.

While the Age of Reptiles was in progress, true Birds came into existence. One of the earliest forms was *Archæop'teryx macrou'ra* (Big-tailed Old-flyer), of which a restoration by Owen is given in Fig. 267. It comes from the Jurassic schists of Solenhofen. It had a conspicuously long, vertebrated tail, quill-bearing on each side; and Marsh has recently shown that it possessed teeth. Whether more a bird than reptile is even still a mooted

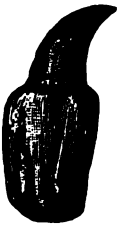


FIG. 270.—Tooth OF *Hesperornis*. × 4.

point. Carl Vogt pronounces it a *feathered lizard*. There are two conical teeth in the upper jaw; eight neck vertebræ, with five pairs of ribs directed backward; ten dorsal vertebræ without

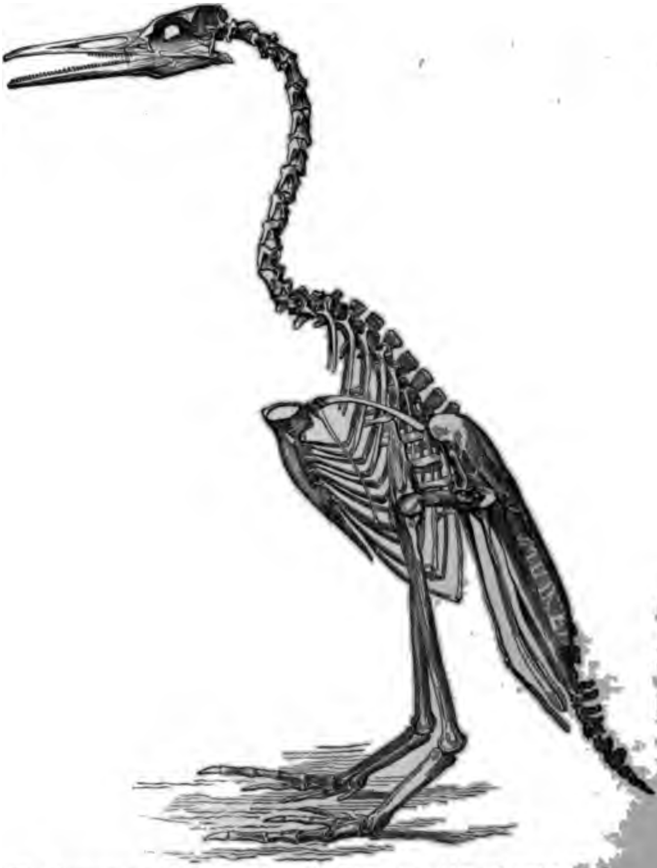


FIG. 271.—SKELETON OF *Hesperornis regalis*, RESTORED. (After Marsh.) × $\frac{1}{10}$.

spinous processes, and supporting ribs without uncinate processes; five sternal ribs, and very minute sternum. The fore limb, he maintains, is *not* a proper wing, and there are three digits, resembling those of a clawed lizard. If the feathers had not been preserved, no one would have thought the *Archæopteryx* a bird, or capable of flight. Here, then, is a creature in which bird and reptile are so mixed that the best judges cannot agree whether it is one or the other.

Equally remarkable forms have been described by Marsh, from American Cretaceous strata, on which he has founded the Sub-Class ODONTORNITHES, with two Orders, *Odontolcæ,* having teeth in grooves, and *Odontotormæ,* having teeth in sockets. The tail was not specially elongated. Some of their characters are illustrated in Figs. 268–271.

These "connecting links" between reptiles and birds possess extreme interest. Whatever conclusions they may sustain respecting the genetic relationship between these two types, externally so dissimilar, the nature of the structural relations is identical with that which runs through all the numerous and diversified Orders of reptiles, and also allies reptiles with all the other vertebrate classes.

§ 10. **Mammals.**

1. *Mesozoic Mammals.* The earliest discovered traces of Mammals occur in the Upper Triassic strata of the Old World, and in strata of nearly the same age in America. They are single species in each case. The next remains occur in the Jurassic. The Cretaceous passes with the disclosure of only a single relic, found in America. But, with the opening of the Cænozoic Æon, mammalian life appears to have been abundant.

The Triassic Mammal of Europe has been named *Microlestes antiquus*; that of America, *Dromatherium sylvestre,* Emmons, from the red sandstones of North Carolina. These have been generally regarded as Triassic; but Professor Fontaine's recent determination of the Jurassic age of the Richmond and Deep River

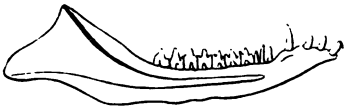


FIG. 272.—LOWER JAW OF *Dromatherium sylvestre*, EMMONS, FROM THE JURA TRIAS OF NORTH CAROLINA. (After Emmons.)

coal fields may fix a later epoch for *Dromatherium*. The Triassic mammal of South Africa is ***Tritylodon longævus*** (Owen), as large as a gray fox, and remarkably specialized for a mammal so ancient.

Judging from a single ramus of the lower jaw of *Dromatherium*, Fig. 272, the animal was an insectivorous Marsupial, related to the Banded Anteater of Australia, ***Myrmecobius fasciatus***, Fig. 273. ***Microlestes*** is believed to be nearly related.

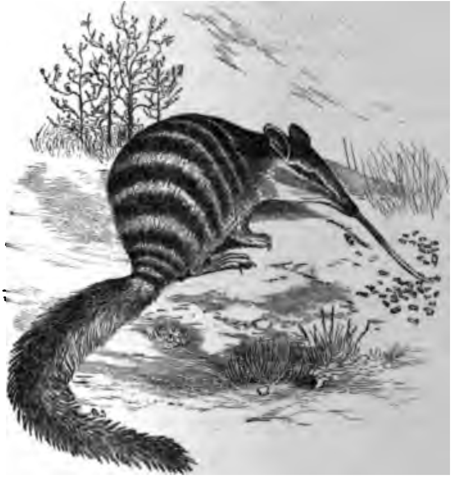


FIG. 273.—*Myrmecobius fasciatus.* THE BANDED ANTEATER OF NEW SOUTH WALES. × ⅓. (After Gould).

The next horizon of mammalian remains is, in the Old World, in the Stonesfield Slate of the Lower Oölite. According to common opinion, they all belonged to Marsupials. *A*
(Fig. 274), *Amphilestes* and *Phascolotherium* (Fig. 2
also, probably, Insectivores. *Stereognathus* appears to
herbivorous. Toward the close of the Oölitic period,

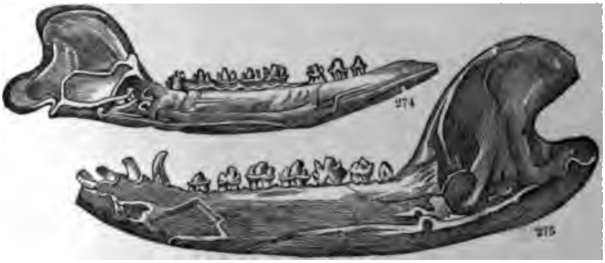


FIG. 274.—*Amphitherium* (*Thylacotherium*) *Broderipii.* × 2. FIG. 275.—*Phasco*
rium Bucklandi. × 2.

Purbeck beds supply another deposit of small mammalian remains, amounting to 14 species, all considered marsupial and polyprotodont — that is, having more than two lower incisors, with canines more or less extensively developed, and the molars either cuspidate or with sectorial crowns. Of these, *Plagiau'lax* is allied to the Kangaroo rats, having large premolars with seven conspicuous grooves on the crowns. The other genera, *Spalacothe'rium*, *Tricon'odon*, and *Galastes* are Insectivores; and related to Australian Phalangers. *Perathe'rium*, from the Paris and American Eocene, was an opossum.

The Atlantosaurus Beds of the American Jurassic have yielded not less than 17 species of mammals, all of which are probably marsupial or related to marsupials, and most of which are insectivorous, and related to European forms. *Dryoles'tes priscus* was a small opossum. Four other species of *Dryoles'tes* are known. *Stylac'odon*, 2 species, was a near relative of the European *Stylodon*. *Ctenac'odon*, 2 species (Fig. 276), was akin to *Plagiau'lax*, and the two are constituted by Marsh the types of a new order, ALLOTHE'RIA, supposed combining marsupial and other characters, and now extinct. The names of the other genera are *Tin'odon*, 4 species, *Dyplocyn'odon* (Fig. 277), *Tricon'odon*, *Al'lodon*, and *Doc'odon*. These Marsh associates in another new order, PANTOTHE'RIA, to which he thinks most of the European Jurassic Mammals belong. With few exceptions, he says, the Mesozoic Mammals are low, generalized forms,

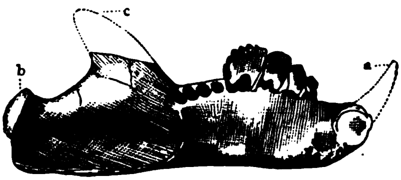


FIG. 276.—*Ctenac'odon serratus*, MH. × 2½. LEFT LOWER JAW. From the Jurassic of Wyoming Territory.

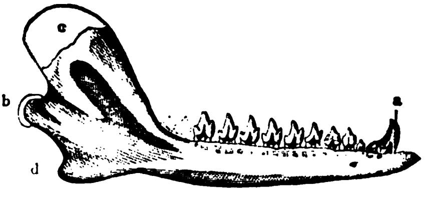


FIG. 277. — *Dyplocyn'odon victor*, MH. × 1½. *a*, incisor: *b*, condyle; *c*, coronoid process; *d*, angle.

without any distinctive Marsupial characters. Not a few of them show features that point more directly to Insectivores. From this Order true Marsupials and Insectivores were probably derived.

From the Laramie, or highest group of the Cretaceous, Cope described, in 1884, a single Mammal, *Meniscoës'sus conquis'tus*, discovered by J. E. Wortman in Dakota. It belongs to the *Plagiau'lax* family.

[illegible] 2. *Tertiary Mammals.* By such beginnings the Mammalian Class was introduced upon the earth. During two entire Mesozoic Ages they were small and feeble creatures, either low Marsupial in type or else even lower than Marsupial, and marking Orders from which the Marsupial characters had not yet been clearly differentiated. It must be said, however, that the Marsupial, after a few oviparous Monotremes, is the lowest known Mammalian organization, and an antecedent improbability exists of any older order generalizing marsupial and placental Mammals.

With the opening of the Tertiary Age a rich mammalian fauna was in possession of the continents — at least of America and Europe. We are unable to say whether they generally possessed marsupial characters or not; but there is little evidence that they did. They are, however, highly generalized forms. None of our modern Orders had become distinctly differentiated, but several of them were pre-indicated with considerable salience. There were characters belonging to Insectivores, Carnivores, Rodents, Pachyderms of different tribes, and even of Proboscidians; but they were variously associated in the same animals. One of the earliest of these comprehensive types in America and Europe was *Coryph'odon*, Owen (including *Bath'modon*, Cope), from near the bottom of the Eocene. An outline of the skull is shown in Fig. 278, in which the small size of the brain is indicated.

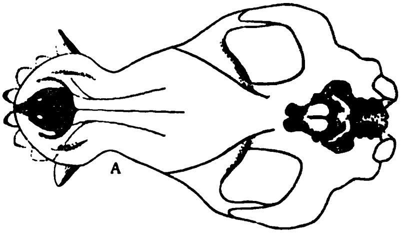
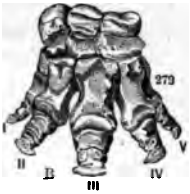


FIG. 278. — *Coryph'odon hamatus.* From Above. (After Marsh.) × ⅛. Lower Eocene.

This was a large tapir-like quadruped. The limbs were short, and each of the feet was supplied with five functional digits (Figs. 279, 280). Cope describes 12 American species of *Coryphodon* and two of *Bathmodon.*



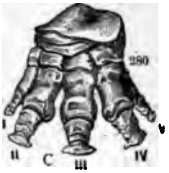


FIG. 279.—LEFT FORE FOOT. $\times \frac{1}{7}$.
FIG. 280.—LEFT HIND FOOT. $\times \frac{1}{7}$.

Of nearly the same age as the *Coryph'odon* was a strange animal which Marsh has named *Tillothe'rium fo'diens*, and made the type of a new Order, TILLODONT'IA. It presents a remarkable combination of the characters of *Ungulata*, *Rodentia*, and *Carnivora*. The skull (Fig. 281) resembles that of a bear, and the skeleton generally is that of Carnivores; but the feet are 5-toed and plantigrade. The premolars and molars have grinding crowns, the canines are of small size, and the premaxillaries carried a pair of scalpriform incisors, like the beaver's in form and in growing from persistent pulps. *Anchippodus*, Leidy (= *Trogosus*), was allied to *Tillotherium.*

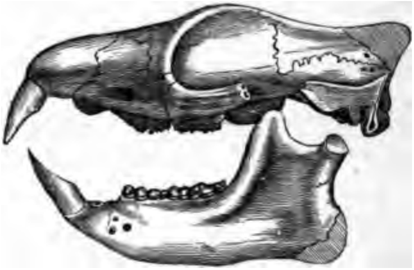


FIG. 281.—*Tillothe'rium fo'diens*, MH. WITH THE LOWER JAW DISPLACED DOWNWARD. $\times \frac{1}{15}$. (After Marsh.)

Another interesting form, from the Wahsatch Eocene of Wyoming, is *Phenac'odus*, Cope, a skeleton of which, in the position in which it was found imbedded in the sand-rock, is shown in Fig. 282. Its nasal bones and several other features resemble the tapir; the tail was as long, proportionally, as that of a cat; the hind feet were semi-plantigrade; the molar teeth were pig-like. Of *Phenacodus* Cope has described thirteen species, and has made it the type of a family and of a Sub-order

CONDYLAR'THRA, which, with *Hyracoidea*, the Conies, he unites in the new Order, TAXEOPODA.

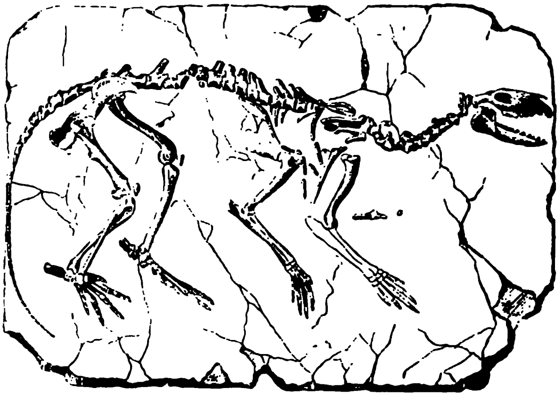


FIG. 282.—*Phenac'odus Wortmani*, COPE. × 1/11. WAHSATCH GROUP, WYOMING. (After Cope.)

Another Wahsatch form, found also in Wyoming, is named *Mes'onyx* by Cope. The lower jaw is here figured. (Fig. 283, *a*, *b*.) This animal was distinctly flesh-eating, but in some respects it differed from modern Carniv'ora, and Cope has established a new Order, **CREODON'TA**, to receive this and numerous other extinct flesh eaters, which he arranges in eight families. They were also related to Marsupials and Insectivores. One group of them (the *Tillodontia* of Marsh) was rodent, with lemurine tendencies, and the other, *Tæniodonta*, was edentate.

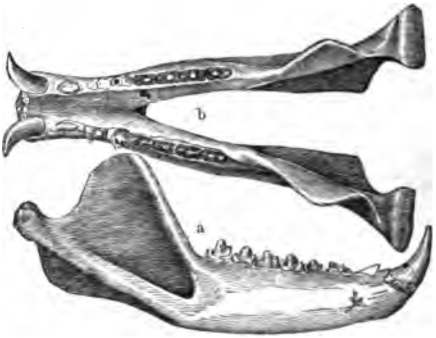


FIG. 283.—*Mesonyx ossif'ragus*, COPE. WAHSATCH OF BIG HORN RIVER, WYOMING. (After Cope.) × ½. *a*, side view of mandible; *b*, view from above.

In the next or Bridger epoch of the Eocene existed in Wyoming an assemblage of quadrupeds elephantine in dimensions and striking in organization. These have been made the subject of an elaborate memoir by Marsh, in which an extinct sub-order has received an elucidation unequalled in the history of science. They have also been very thoroughly investigated by Cope and Leidy, and have been embraced within the researches of Osborne and Spier. The DINOCER'ATA of Marsh are constituted of three genera: *Uintatherium* (= *Bathyop'sis*, Cope), *Dinoc'eras*, and *Tinoc'eras* (= *Eobas'ileus*, Cope). With the DINOCER'ATA Marsh unites the CORYPHODON'TA (= PANTODON'TA, Cope) to constitute the Order AMBLYDAC'TYLA, which appears to be precisely identical with Cope's older named AMBLYP'ODA. This, with the orders PROBOSCID'EA, HYRACOID'EA, and CLINODAC'TYLA (= *Perissodactyla* + *Artiodactyla*) form Marsh's Super-Order UNGULATA. It would be out of place here to enumerate the characters of these genera. The student will get an impression of the aspects of these primitive beasts from the skulls and skeletons here figured. It is obvious that the feet resemble, except in technical points, those of *Coryph'odon*, and also those of the elephant. A cast

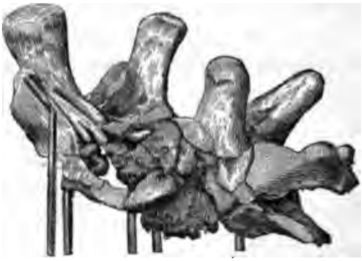


FIG. 284.—*Uintathe'rium Leidya'num*, SKULL. × $\frac{1}{18}$. BRIDGER GROUP. WYOMING. (After Osborne.)

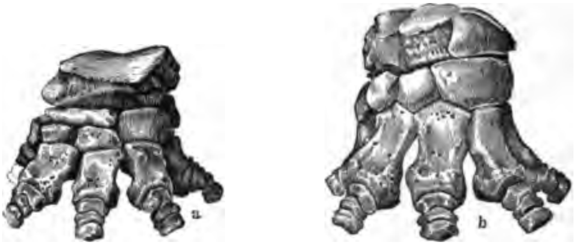


FIG. 285.—FEET OF *Dinoceras mirabile*, MARSH. (*Uintatherium mirabile* of Cope, Leidy, and Osborne.) × $\frac{1}{7}$. *a*, Fore Foot; *b*, Hind Foot. (After Marsh.)

of the brain shows the very small size of the hemispheres and the very large olfactory lobes. The brain is the most reptilian among mammals. In Fig. 286 is a restoration of the skeleton of *Dinoc'eras*. In Fig. 287 is a similar restoration of *Tinoc'eras* or *Eobas'ileus*. The student will notice in all these a similar structure of the feet, and similar protuberances on the skull. It is uncertain whether these were surmounted by horns or only covered by thick skin. In either case, they served, probably, as weapons of attack. The enormous canines served a similar purpose.

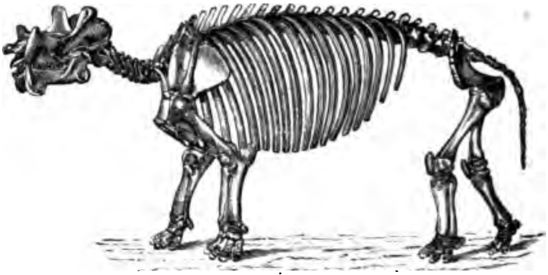


FIG. 286.—*Dinoc'eras mirab'ile*. MH $\times \frac{1}{15}$. BRIDGER GROUP, WYOMING. (After Marsh.)

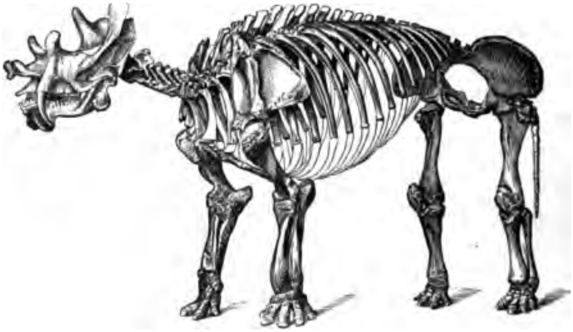


FIG. 287.—*Tinoc'eras ingens*, MH. $\times \frac{1}{45}$. BRIDGER GROUP, WYOMING. (After Marsh.)

The *Dinocerata*, according to Cope, are composed of ***Eobasileus*** (*Tinoceras*, Marsh), *Loxolophodon* (included in ***Tinoc-***

eras by Marsh), *Bathyopsis* (= *Uintatherium*, *pars*, of Marsh), and *Uintatherium*, Leidy.

Passing unmentioned a multitude of remarkable Eocene forms, we reach the White River Beds of the Miocene, and find in existence another type of elephantine quadrupeds. The *Brontothe'rium*, Marsh (= *Symbor'odon*, Cope, + *Miobas'ileus*, Cope), of which a skull is shown in Fig. 288, had four nearly equal toes on the fore foot and three on the hind foot, thus numerically resembling the tapirs. In size and general conformation of the skeleton it resembled the elephant, but with shorter limbs. The nose was probably long and flexible, but without a proboscis. The brain cavity was very small. A pair of horncores rose on the maxillary bones. The canines were short, and separated by a *diastema*, or interval, from the premolars. The student may point out from the illustrations the differences among the great extinct mammals.

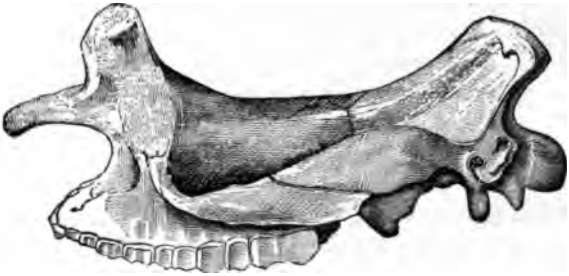


FIG. 288.—*Brontothe'rium ingens*, MH. WHITE RIVER BEDS OF THE MIOCENE. (After Marsh.) × $\frac{1}{12}$.

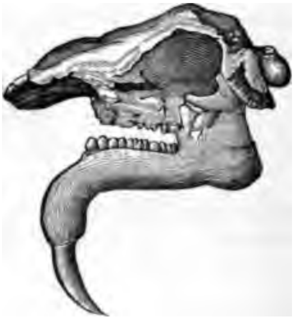


FIG 289.—*Dinothe'rium giganteum*, KAUP. CONTINENT OF EUROPE. (After Kaup.)

The Tertiary ages of other continents were equally productive of mammalian forms; but we can only afford space for mention of two. The *Dinothe'rium* was about the first known of Proboscidians. Its remains have been found in Germany, France, and Greece, in deposits of Miocene age. It had in the lower jaw two enormous tusk-like incisors, directed vertically downward. The molars present a combination of mastodont and tapiroid characters. The animal attained enormous size, and by some it is thought to have been of semi-aquatic habits. The other foreign mammal to be mentioned is the *Sivathe'rium* of the Sivâlik Hills in India, a gigantic four-horned Antelope. The posterior horns possessed two snags or branches, a peculiarity not to be paralleled among existing *Cavicor'nia*, except in the Prong-buck. *Bramathe'rium* was a contemporary of similar organization.

We must mention, lastly, the succession of horse-like forms that have existed in America during the progress of the Tertiary ages. These have been worked out by Marsh, to whom science is indebted for so many important results. Much, however, has been contributed by Cope and Leidy, and it is not certain that some of their names are not possessed of priority over Marsh's.

Animals somewhat horse-like were in existence at the beginning of the Eocene. Other species appeared in succession, progressively more and more like the modern horse, until, near the close of the Tertiary, the modern genus *Equus* appeared. It would not be proper to enter here into the details which characterize and differentiate these successive equine forms; but the student may refer to the illustrations, Fig. 290, while he reads the following brief statements:

In the oldest Eocene deposits of New Mexico are found the remains of a horse-like quadruped, *Eohippus* (= *Hyracothe'rium?*), about the size of a fox. It had four functional toes before and three behind, thus resembling the tapir. A rudiment (like a "splint bone") remained of the outer or Vth toe behind (since those present were the IId, IIId, and IVth); and since the Vth was present before, there was *probably* a rudiment of the Ist in the fore foot, making the normal number of five digits in that foot. The "hoofs" were mere thick, broad, and blunt claws. The molars were short and without "cement." There were

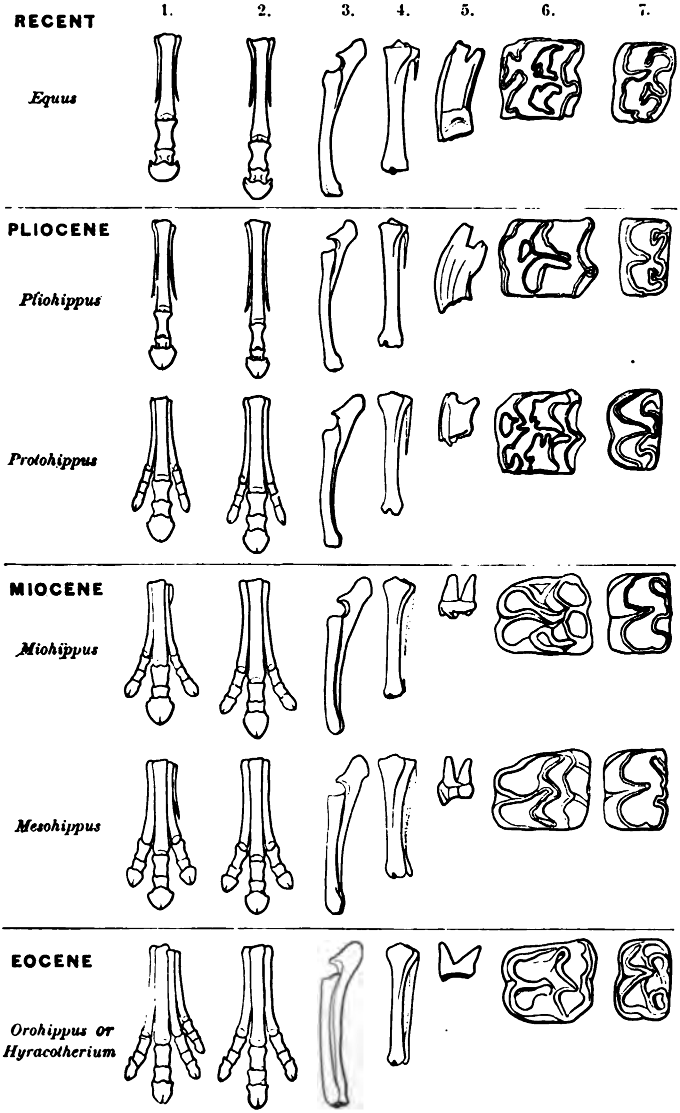


FIG. 280.—SUCCESSION OF EQUINE TYPES. (Marsh.) See Explanation, page 354.

eight carpal bones, resembling those of the tapir. This genus is not illustrated in Fig. 290.

In the Middle Eocene or Bridger Beds, of Wyoming and Utah, existed *Orohippus*, also of the size of a fox. This had four functional toes before and three behind. The ulna was complete and distinct from the radius. The tibia and fibula were also distinct. The crowns of the molars were exceedingly short, and the enamel pattern simple. Later in the Eocene lived *Epihippus* which resembled *Orohippus* in the digits, but differed in its more developed molars.

In the early Miocene lived *Mesohippus*, a horse-like quadruped of the size of a sheep. Its functional toes had diminished to three before, nearly equal, and three behind. In the fore limb, however, was a large "splint," the remnant of the Vth digit of *Orohippus*. The radius and ulna were still distinct, but the latter was considerably attenuated in the lower part. The tibia and fibula were also distinct.

In the late Miocene of Oregon existed *Miohippus*, a of the
size of the sheep, with three functional toes before and e behind, and also a splint of the Vth digit before, but
Mesohippus. The middle hoof is also larger and the late
are shrunken. The ulna is still distinct and as long as the
but very slender distally. The fibula is coössified
at the lower end. The older Miocene *Anchitheri*
equine known in Europe, is closely related, but a lit
specialized.

Coming down to the early Pliocene, we find that
quadruped existed, called *Protohippus*, of the s
Instead of three serviceable toes it had but one with a
hooflet or "dew-claw" on each side. The ulna was as
the fore arm, but extremely slender. The fibula
tary. The crowns of the molars were still longer
hippus. Contemporary with this, were the sely
chippus in America and *Hipparion* (=
Europe; while *Merych'ius* was probably ident

Next, in the Middle Pliocene, existed *Plio* portions of a moderate-sized horse, in which was only a median toe, larger than in *Protohippus*, but with large splints instead of dangling hooflets, on each side. The crowns of the upper molars were longer and the crescentic areas more complicated than in the older types.

Finally, toward the end of the Pliocene, *Equus*, the modern horse, existed in America. It differred from *Protohippus* in a more powerful middle digit, diminished splint bones, upper molar crowns larger and more elongated, and crescentic areas, formed by the enamel plates, more complicated. The horse subsequently found its way to the Old World and remained to historic times. Meantime it became extinct in America, and was reintroduced on the discovery of the New World by civilized man.

The historical vicissitudes of the Camel have been similar. These and many other facts indicate that the Old World received some of its Mammalian populations from the New.

§ 11. Retrospect of Succession of Vertebrate Life in America.

The following Table, compiled from final publications of Marsh and Cope, exhibits the order of introduction of the principal vertebrate types in America, with a corresponding grouping of formations. The student of geology will find it useful for reference.

SUCCESSION OF VERTEBRATE LIFE IN AMERICA.

CÆNOZOIC.	**Recent**			Tapir, Peccary, Bison, Llama.
	Quaternary.			*Bos, Equus, Dicot'yles, Mas'todon, Elephas, Megal'onyx, Castoroides.*
			Equus Beds "Post Pliocene."	*Equus, Tapirus, Elephas.*
	TERTIARY.	LOUP FORK	Pliohippus Beds	*Procamelus* and *Ticholeptus* Beds (Cope). *Pliohippus, Protohippus, Blastomeryx, Palæolagus, Hyracodon, Oreodon, Procamelus, Tapiravus, Mastodon, Aceratherium, Bos, Morotherium, Merychius, Anchippus, Styl'onus.*
		WHITE R.	Miohippus Beds	*Miohippus, Diceratherium, Thinohyus.*
			Oreodon Beds	*Ore'odon, Epore'odon, Hyæn'odon, Hyrac'odon,* Edentates. *Moropus.*
			Brontotherium Beds	*Brontotherium, Men'odus, Mesohippus, Elotherium, Poëbrotherium, Hypertragulus, Didelphys.*
		UINTA	Diplacodon Beds	*Diplacodon, Epihippus, Amyn'odon* (Perissodactyl) *Hyop'sodus* (Mesodont.) *Agriochœrus.*
		BRIDGER	Dinoceras Beds	*Dinoceras, Tinoceras* or *Eobasileus, Uintatherium, Bathyopsis, Loxolophodon, Orohippus, Palæos'yops, Hyrach'yus, Lymnohyus, Helale'tes, Colonoc'eras.*
		GREEN R.	Heliobatis Beds	*Heliobatis, Amia, Lepidosteus,* Crocodiles. *Clastes, Priscacara.*
		WAHSATCH	Coryphodon Beds	*Coryphodon, Phenacodus, Hyracotherium, Eohippus, Oxyæna, Meniscotherium.* Lemurs, Creodonts, Ungulates, Tillodonts, Rodents, Serpents.
		PUERCO	Champsosaurus Beds	*Champsosaurus,* Marsupials, *Ptilodus, Catopsalis.* Omnivore. *Catathlæus.* Tillodont, *Psittacotherium.*
MESOZOIC.	CRETACEOUS.	LARAMIE	Hadrosaurus Beds	*Hadrosaurus, Dryptosaurus* (*Lælaps*), *Cionodon, Diclonius, Champsosaurus.* Only Cretaceous mammal *Meniscoëssus.*
		FOX HILL		Procœlous Crocodiles.
		COLORADO	Pteranodon Beds	*Odontornithes* (Toothed Birds): *Hesperornis, Ichthyornis.* Mosasaurs: *Edestosaurus, Lestosaurus, Tylosaurus.* Plesiosaurs: *Elasmosaurus, Polycotylus.*
		DAKOTA		
	JURASSIC		Atlantosaurus Beds	Dinosaurs: *Atlantosaurus, Brontosaurus, Morosaurus, Diplodocus, Stegosaurus, Camptonotus, Allosaurus.* Turtles. Crocodiles. Mammals: *Dryolestes, Stylacodon, Tinodon, Ctenacodon.* Bird: *Laopteryx. Baptanodon.*
			Baptanodon Beds	
	TRIASSIC		Otozoüm Beds	First Mammals: *Dromatherium.* Dinosaur Foot-prints. *Amphisaurus.* Crocodiles: *Belodon.*
PALÆOZOIC.	CARBONIF.	PERMIAN	Nothodon Beds (Marsh)	Reptiles: *Nothodon, Sphenacodon* { Clepsydrops Shales, Eryops Beds. } Cope.
		COAL MEAS.	Eosaurus Beds	First Reptile? *Eosaurus.* Amphibians.
		LOWER CARB.	Sauropus Beds	First known Amphibians (Labyrinthodonts), *Sauropus.*
	DEVONIAN		Dinichthys Beds	*Dinichthys, Onychodus. Macropetalichthys.*
	SILURIAN			*Palæaspis. Onchus.* } First known Vertebrates.

§ 12. Conspectus of the Geological Range and Relative Expansion of the Principal Types of Animal Life.

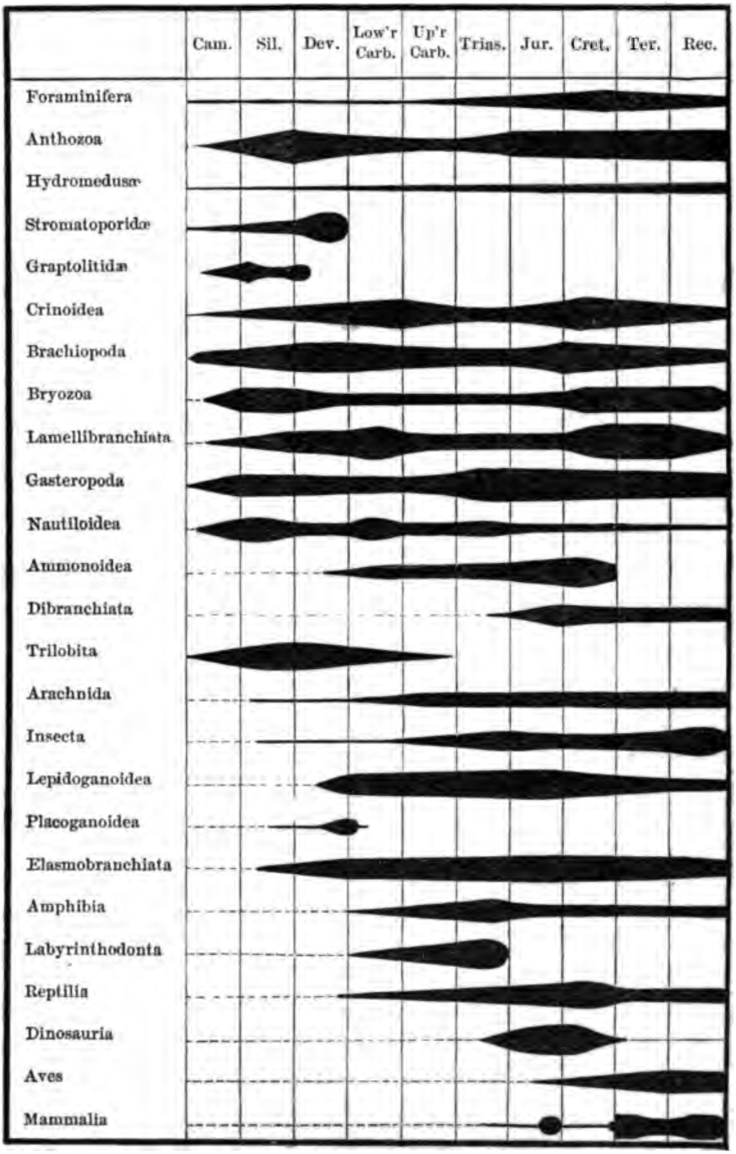


FIG. 291.—TABLE OF RANGE AND EXPANSION OF ORGANIC TYPES.

CHAPTER V.

FORMATIONAL GEOLOGY.

FORMATIONS, THEIR STRATIGRAPHICAL CONSTITUTION, GEOGRAPHICAL EXTENSION, AND PALÆONTOGRAPHICAL CHARACTERISTICS.

§ 1. Preliminaries. Geological Maps.

WE must now return to the rocks, and learn more methodically what are the lithological characters of the various groups into which they are arranged, as heretofore shown (page 274), their thickness and relative importance, the fossil remains which characterize them, and the regions in which they occupy the earth's surface.

By the aid of the classification which has been already studied to a considerable extent, and the geological map of the Eastern United States, on which numerous exercises have been had, with the general survey of organic life contained in the last chapter, a good preliminary acquaintance has been made with the formations which we are now to study a little more in detail, or at least in a somewhat different manner.

To prepare the way for a broader and completer comprehension of American geology, we now direct the particular attention of the student to both parts of the Geological Map of the United States on pages 118 and 119.

To enable the student to acquire a grasp of the method of continental development, we also introduce here a very general map of the geology of North America :

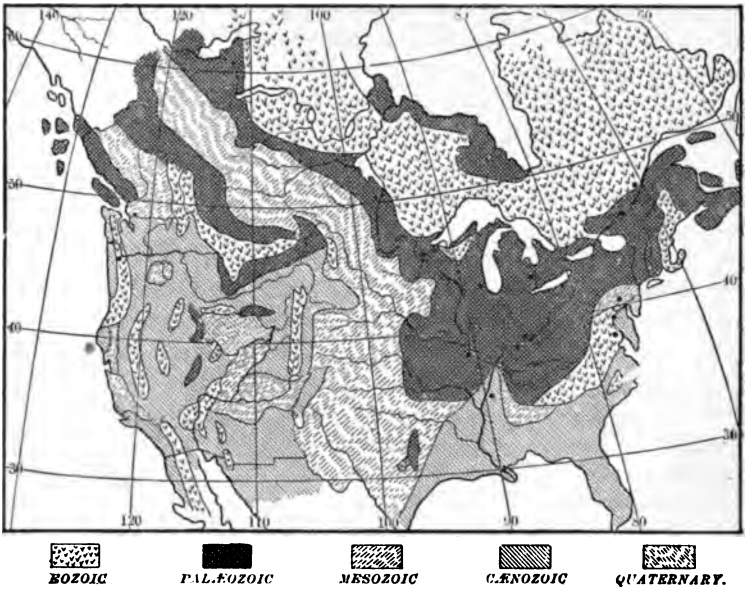


FIG. 292.—GEOLOGICAL MAP OF NORTH AMERICA.

§ 2. The Eozoic Great System.

1. *How the Term is Used.* A glance at the geological maps shows that the rocks of this Great System occupy but comparatively little of the actual surface of North America. But when we reflect that they pass everywhere under the other rocks, we understand that they constitute the great mass of the solid land. Because they constitute the beginning of the *actually observed* series of formations, some geologists designate them *Archæan*, from ἀρχή, the *beginning.* But we know too little about the deepest and oldest rocks to assert that formations seen at the surface continue down and include the rocks formed *in the beginning.* We have good reason to believe, as before explained (page 288), that the beginning rocks have been long ago melted away. We do not know that any archæan rocks remain. Assuredly, we have not seen any archæan rocks; and it is certain they are not strati-

fied, as the oldest rocks known to observation are. We may reason about archæan rocks, as a necessity of our theory of the world. We may even extend the meaning of the term to embrace all the rocks from the beginning of incrustation to the Cambrian. We may sometimes use the term in this sense. But we need a term to designate these later archæan rocks, and hence we style them *Eozoic* — a term symmetrical with Palæozoic, Mesozoic, and Cænozoic, and one which, unlike *Azoic* (formerly employed), can never become inapplicable through the progress of discovery. The rocks next before the *Eozoic* were perhaps strata now melted away. Before all strata there must have existed a *fire-formed* crust — a real *Pyrogenic* formation. Hence, *Archæan*, in the sense suggested, is comprehensive, and we need to note its divisions.

2. *Divisions of the Great System.*

Eozoic Great System.	Keweenian System. Huronian System. Laurentian System.

The name Azoic was applied to rocks older than the lowest known fossiliferous strata by Messrs. Foster and Whitney in their Government report on the Mineral Region of Lake Superior. By Sir William Logan and his associates rocks holding this position in Canada were divided into Laurentian and Huronian, from the Laurentide Hills and Lake Huron. Very much discussion has been subsequently had, and is still in progress, respecting the classification of these pre-Cambrian rocks; and this has acquired new interest in connection with the public surveys still in progress in Minnesota, Wisconsin, and Michigan. Western studies seem to have established the existence of a Copper Bearing (Keweenawan or Keweenian) Series above the proper Huronian and older (as is now thought) than the Cambrian. This System we accordingly introduce here, for the first time, we think, in any text-book.

At the same time, this arrangement must be regarded as provisional. It will be shown in the next Section that an "Acadian" or "St. John" formation is known on the eastern border of the continent, and also in Central Nevada, holding a position beneath the Potsdam formation. This Acadian is not identified in the Upper Mississippi region; and it may yet be shown that the Keweenian is its chronological equivalent. Again, it has very recently (September, 1885) been shown, by N. H. Winchell, that Cambrian fossils occur in the "Pipestone" of the Upper Missouri River. As the pipestone is embraced in the great Quartzite formation underlying the Potsdam in Minnesota and Wisconsin, the evidence is that this Quartzite is Cambrian, as the present writer long ago suggested, instead of Huronian, as maintained by the Wisconsin geologists. If so, it is in the position of the St. John Slates of the East, and may be their western equivalent. Like the Keweenian, it succeeds downward the Potsdam Sandstone; and the question remains open, What are the relations between the Copper Bearing Series and the Baraboo Quartzite?

3. *Geographical Distribution of Surface Exposures.* Eozoic rocks at present occupy the surface (1) in regions where no later sediments were ever deposited over them in consequence of the uplift of those regions above the sea level; (2) in regions once overlaid by later sediments which have been carried away by erosions; (3) in places where they have been thrust up through breaches in the overlying strata.

Glancing over the Geological Map, we notice one principal belt stretching from the coast of Labrador to the region north of the Great Lakes, and thence northwest to the Arctic Ocean, covering an area enclosing Hudson's Bay like an arc of a great circular belt. It will be noticed that the Adirondac area is an appurtenance to this, and that an arm stretches southwestward into Minnesota. The considerable area in Michigan and Wisconsin may be regarded as simply an outlying patch of the same. This is the great Eozoic *nucleus of the continent*—at least of its eastern and northern parts. It is the *Great Northern Eozoic Belt.* We find also an Appalachian belt stretching from Dutchess county, New York, and, with some interruptions, from New Brunswick to Georgia. This is the *Great Seaboard Eozoic Belt.*

Over the Rocky Mountain region, and westward at intervals as far as the Sierra Nevada, occur isolated areas and outcropping mountain masses and ranges of Eozoic rocks which have been largely concealed by later sedimentation. This is the *Great Cordilleran Eozoic Area.* Other detached island-like areas exist in Missouri, Texas, and other regions.

4 *General Constitution of the Great System.* The Eozoic rocks, as far as accessible to us, attain an enormous thickness. We have studied probably 95,000 feet of them — not all, of course, in one connected series. We find them to be almost wholly crystalline and hard. The greater part are phanerocrystalline. Nearly all known minerals are embraced in them; the majority are even restricted to them. Here are found in place those metamorphic rocks whose kinds we have already studied in the bowlder fragments scattered over the Northern States. Here are the great masses of granites, gneisses, diorites, and diabases, whose stratification has become nearly or quite obliterated. Here are most of the different species of schists. Here are the marbles and serpentines. In these old crystalline rocks are enclosed the great deposits of iron ore — magnetite, hæmatite, titaniferous iron, and Franklinite, or zinc-iron ore. Here are our stores of graphite and soapstone (steatite and parophite).

These rocks show almost everywhere evidences of great disturbance. They have sometimes been tilted up at steep angles. Sometimes they are quite vertical. Very commonly later strata rest on the exposed and worn edges of the Eozoic. In Fig. 38 we have an illustration. On the left are gneisses, *b*, dipping to the left, and resting against the central mass of granite, *a*. On the right are gneisses, *b*, dipping toward the right at a steep angle, and resting against the other slope of the granite nucleus. On the upper edges of these thick-bedded gneisses rest unconformably the strata of sandstone, *c*. The latter are not Eozoic. The gneisses were tilted before the sandstones were laid down. A geological convulsion here separates two ages and two formations. In Fig. 107 the horizontal sandstones, *S*, are seen abutting against the slope of the older rocks, *C*, and the underlying and still older beds, *H*, rest against broken edges of the formation, *L*. The relation of the Eozoic to the later formations is well shown, also, in Figs. 46 and 84.

The plication of the Eozoic strata is something as remarkable as their tilting. The section of the Wisconsin rocks, Fig. 293, shows their condition and their relation to the higher rocks. In Mt. Kearsarge, Fig. 89, we find another instructive example of plications. In Fig. 294 we reproduce, from Sir William Logan, a section through the Eozoic strata of western Canada. Here the crumpled condition of the strata is strikingly shown. The dotted lines are intended to indicate the probable connections of the formations.

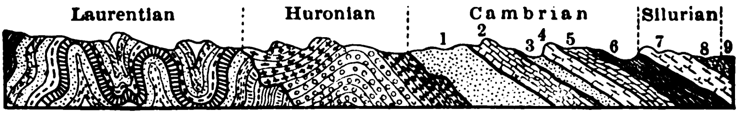


FIG. 293.—GENERALIZED SECTION ACROSS THE ROCKS OF WISCONSIN. (Chamberlin.)
1. Potsdam Sandstone. 2. Lower Magnesian Limestone. 3. St Peter's Sandstone. 4. Trenton Limestone. 5. Galena Limestone. 6. Cincinnati Shales. 7. Niagara Limestone. 8. Lower Helderberg Limestone. 9. Hamilton Limestone.

5. *Kinds of Rocks and Economic Products.* The Laurentian System contains great beds of granite, syenite, and gneiss, with some mica- and much hornblende-schist. Hornblende and pyroxene are very abundant minerals, and with them labradorite is one of the commonest feldspars. Iron is very generally disseminated, both as a chemical constituent and also as a mineral in the forms of magnetite, hæmatite, and titaniferous iron. There are also, in Canada, three great beds of crystalline limestone (Fig. 294), with many intercalated layers of gneiss and rocks consisting largely of pyroxene or hornblende. The Laurentian rocks were estimated by Logan at 30,000 feet.

The Huronian System, as commonly understood, is composed of beds of granular and conglomeritic quartzites, quartz-schists, jasper and chert schists, and several thick formations of diorite and diabase which sometimes pass into granites and syenites; with also a great thickness, higher in the series, of hydro-mica and magnesian schists, and black slate and ferruginous schists, terminated by enormous beds of mica schist, gneiss, and granite. The conglomerates contain rounded fragments up to a foot in diameter, and with the quartzites, attain a thickness of 2,500 feet. The great iron deposits of northern Michigan and Wisconsin are associated with quartzose and dioritic rocks, and are commonly regarded Huronian.

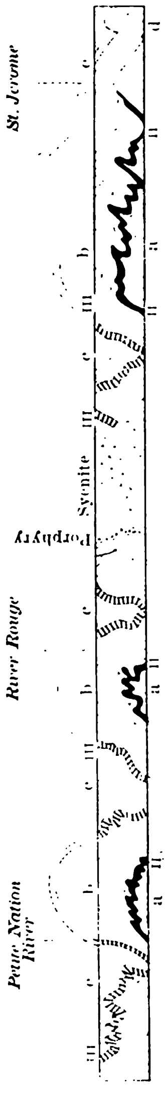


FIG. 294.—EAST AND WEST SECTION ALONG THE NORTH SIDE OF THE OTTAWA RIVER, CANADA. (Logan.) a, a, a, Second Gneiss. b, b, b, Third Gneiss. c, c, c, Fourth Gneiss. d, e, Upper Laurentian. II and III, Second and Third Limestones—the latter with *Eozoön*.

The Keweenian System consists of interstratified igneous and sedimentary beds. The former are mainly diabases, with some norites,* melaphyrs, and porphyries; the latter are conglomerates, sandstones, and shales derived mainly from the igneous rocks. The conglomerates are formed of the *débris* of felsitic and quartz porphyries, with some from diabases. Some of the conglomerate fragments are one or two feet in diameter. A single bed of coarse conglomerate on the Montreal River is 1,200 feet thick. The beds are tilted, but not contorted, and metamorphic. Maximum thickness about 45,000 feet, of which over 15,000 feet are sedimentary. Irving separates them into an Upper division wholly sedimentary — mostly red sandstone and shale — with a mean thickness of 15,000 feet, and a Lower division made up chiefly of basic igneous rocks in many sheets, with a thickness of 25,000 to 30,000 feet.

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* These by the Wisconsin and Minnesota geologists, following late German authorities, are termed "gabbros"—a name which ought to be allowed to rest in disuse. (See pages 58 and 77, this work.) *Gabbro* is defined in the Wisconsin Report as follows: "A rock formed of a *plagioclase* feldspar and *diallage*. The feldspar is usually *labradorite*. The diallage is little more than a foliated augite. Usually more coarsely crystalline than diabase. The Duluth granite is a typical example." *Norite* with them is composed of a *plagioclase* with *hypersthene* or *enstatite* (similar to hypersthene, but light-colored). See page 77.

Geologists are not united as to the geological position of the great iron-ore beds. Those of northern New York (See Figs. 103 and 104) and Missouri are commonly represented as Laurentian, and the similar beds in North Carolina, Canada, Sweden, and Norway are believed to be of the same age. But the Pilot Knob and Iron Mountain deposits are not far remote stratigraphically from the Lower Magnesian (Cambrian) limestone. The section through the Penokie Iron Range, too, Fig. 107, shows the iron-bearing beds included conformably in the Huronian, *H*, while these strata rest quite unconformably against the edges of the Laurentian strata, *L*. Not unlikely, the rocks inclosing the iron ores of northern New York will be found to be Huronian.

The mode of occurrence of iron ores and other particulars will be found elsewhere (pages 182, 69).

The great copper deposits of the Lake Superior region occur in the Keweenian series. They exist partly in the igneous rocks and partly in the sedimentary. In the latter, they appear to be mostly a secondary product, introduced after the sediment was laid down. In some cases the metal appears as an original constituent of the conglomerate. In the Calumet and Hecla mine, the most productive in the world, the so called vein is simply a conglomerate 8 to 12 feet thick, lying between massive sheets of trap. The native copper permeates the whole mass, and serves as a cementing material. In the trap rocks the copper is found filling, either alone or with other minerals, the amygdaloidal cavities which abound near the lower and upper surfaces of the sheets, and insinuating itself into the other cavities and fissures. Sometimes the filled fissures assume the characters of true veins.

From rocks of Laurentian age comes most of the graphite of the world. (See Part I, Study XIII.) They afford, also, apatite, a phosphate of lime used in agriculture; rensselærite or steatite, used for potstone or soapstone, and cut into slabs for chimney pieces, furnace linings, and foot warmers, and used also for inkstands; parophite, an aluminous rock used for inkstands; beds of marble. Formations perhaps later in the series contain slates and deposits of lead and zinc ores.

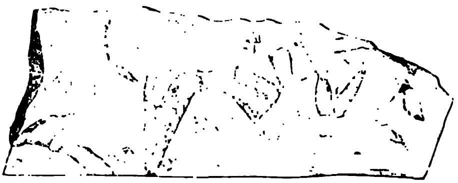


FIG. 295.—*Palæophycus arthrophycus*, WIN. FROM THE KEWEENIAN SANDSTONE, NORTH FLANK OF THE PORCUPINE MOUNTAINS. (From Nature.)

6. *Organic Remains.* The great deposits of iron ore and graphite have long been regarded as evidence of the presence of organization early in the Eozoic Æon. But no organic forms are known in the Laurentian or Huronian systems except Eozoön.

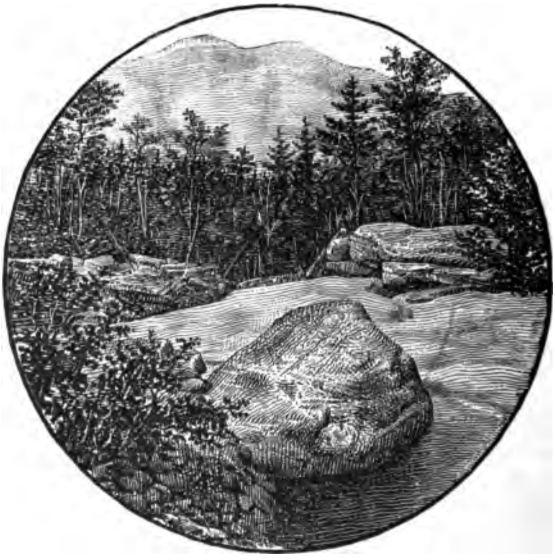


FIG. 296.—MT. KEARSARGE AMONG THE WHITE MOUNTAINS. SHOWING FORMS ASSUMED BY EOZOIC FORMATIONS IN PROCESS OF WEATHERING. BOWLDERS IN THE FOREGROUND. See section through this mountain, Fig. 62.

Of this enough has already been said (pages 318–320). In the Keweenian sandstones of the north flank of the Porcupine Mountains Dr. D. Houghton collected, many years ago, some remains which appear to belong to marine plants, and these the author has described as *Palæophycus arthrophycus* and *P. articulatus*. They are quite as definite in form and characters as any previously described from the Cambrian. A representation of one of these is shown in Fig. 295.

§ 3. The Cambrian System.

1. *Divisions, Subdivisions, and Terms.*

CAMBRIAN SYSTEM. [Formations named in natural order of sequence downward. Numbering is from below.]

- III. **Trenton Group** (4).
    - 3. CINCINNATI STAGE (4*c*). The Hudson River shales and slates; Lorrain shales of New York; Nashville Group of Tennessee.
    - 2. UTICA STAGE (4*b*).
    - 1. TRENTON STAGE (4*a*): (3) Trenton limestone; Galena limestone of Illinois; Lebanon limestone of Middle Tennessee. (2) Black River limestone. (1) Birdseye limestone.
- II. **Canadian Group** (3).
    - 3. CHAZY STAGE (3*c*). Chazy limestone, New York and Canada.
    - 2. QUEBEC STAGE (3*b*). Canada, near Quebec; shales, limestones, and sandstones, Newfoundland. Part of Knox Group, Tennessee.
    - 1. CALCIFEROUS STAGE (3*a*). Northern New York. Lower Magnesian limestones of Mississippi valley; St. Peters sandstone, Wisconsin and Illinois; Knox sandstone, East Tennessee.
- I. **Primordial** or **Potsdam Group** (2).
    - 2. POTSDAM STAGE (2*b*) Sandstone of Northern New York, of the south shore of Lake Superior east of Keweenaw Point, and most of that of Minnesota and Wisconsin. Chilhowee sandstone of Tennessee. Georgia slates of Vermont.
    - 1. ACADIAN or ST. JOHN STAGE (2*a*). St. John Group of New Brunswick; beds of St. Johns and elsewhere in Newfoundland; slates of Braintree, Mass.; Ocoee conglomerate and slates of Eastern Tennessee and North Carolina.

The term "Cambrian" has been employed in various senses, and not unfrequently as equivalent to what is here denominated "Primordial." The sense here employed is that announced by the Director of the United States Geological Survey as the one adopted for official use. (Report of the Director for 1881, page xlviii.) It is equivalent to "Lower Silurian" as employed till recently by most American geologists. The name itself comes from *Cambria*, the ancient name of Wales, and was first used by Sedgwick for fossiliferous rocks older than those by Murchison denominated "Silurian," from *Silures*, the designation of the ancient inhabitants of Wales. "Primordial" was employed by Barrande for the lowest fossiliferous zone of Bohemia. "Potsdam" is so named from Potsdam, in New York, and the other terms are geographical in their origin, requiring no explanation, it being as a rule understood that a locality or region giving its name to a formation is one at which the formation was first scientifically described and defined with the limitations now employed by geologists. (See Chap. II, § 4, 3 (6).)

2. *Geographical Extension.* Turning to the Geological Map, we find the Cambrian strata generally resting against the flanks of the Eozoic hills and mountains. Thus, in Canada the valley of the St. Lawrence River is underlaid by Cambrian strata. A large basin, including Montreal and Ottawa, indents the Eozoic area, and a belt of these rocks sweeps around the Adirondac region, crossing the St. Lawrence at Ogdensburg, bordering Lake Ontario on the north, passing under Georgian Bay, rising above the surface on the chain of Manitoulin Islands, sweeping from St. Marie's River to Marquette, thence passing southwestward around the Michigan-Wisconsin Eozoic, and expanding southward over southern Wisconsin, and northwestward to Minneapolis, and beyond. In the valley of the Red River the Cambrian reappears, and stretches far toward the northwest. A large part of Vermont, New Hampshire, and Maine is occupied by Cambrian and Silurian rocks. These strata come to the surface over a large area, embracing the cities of Cincinnati, Madison, Frankfort, and Lexington (Ky.); also over another area embracing Nashville, Lebanon, Columbia, Franklin, and Murfreesboro in Tennessee. An important belt of Cambrian and Silurian undivided is involved in the folds of the Appalachian Mountains. In

southeastern Missouri is a considerable area stretching over into Indian Territory.

3. *The Continent at the Beginning of the Cambrian Age.* At the beginning of the Eozoic Æon — that is, when the sediments began to be deposited which were destined to form the rocks of the Eozoic Great System, the regions now occupied by those rocks must necessarily have been under water. If there were any lands existing whose wastage during Eozoic time supplied materials for Eozoic sediments, we do not know where they were. They seem to have been completely obliterated. If we were to represent America at the beginning of Eozoic time, we could only represent an expanse of water. At the end of the Eozoic Æon, however, uplifts took place ; dry lands appeared. More likely, numerous uplifts had taken place during the progress of the Eozoic.

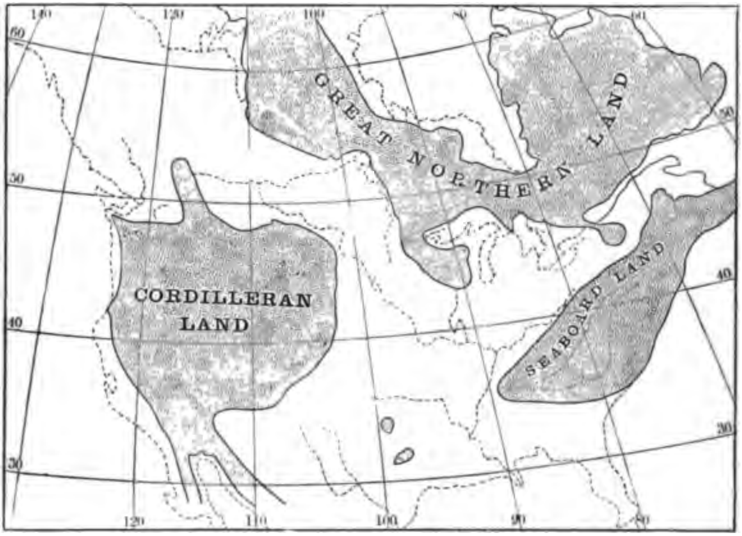


FIG. 297.—NORTH AMERICA NEAR THE CLOSE OF THE EOZOIC ÆON. Based on the latest publications of the Canadian Survey, and the general views set forth by King in the Report on the 40th Parallel Survey.

It will be noticed that the continent of Cambrian time consisted of three great nuclear areas, corresponding nearly to the great Eozoic areas already pointed out in existing surface geology. (1). The Great Northern Area. This was arcuate, stretching from the region of the Great Lakes northwest to the Arctic ocean, and northeast to the coast of Labrador, or perhaps far beyond. (2) The Seaboard Area. This seems to have stretched from New Brunswick southwestward to Alabama, with a breadth varying from 75 to 125 miles, diminished in the latitude of New Jersey. There are reasons to suppose its breadth was much greater on the eastern side, and that it continued over Nova Scotia and Newfoundland. (3) The Great Cordilleran Area. This spread uninterruptedly in width from the western border of Great Plains into western Nevada. It was probably 750 miles in breadth, but its extent north and south has not been ascertained. This land was a great mountain system, displaying lofty ranges made of crumpled strata, enormous precipices, a result of mechanical dislocations, and finally a type of mountain sculpture of such broad, smooth forms as to warrant the belief that subaerial erosion had never carved and furrowed the mountain flanks with the sharp ravines characteristic of modern mountain topography. The evidences on which these conclusions are based will be partially disclosed in describing the results of later geological actions in the same region. This massive belt of Eozoic Cordilleras determined the limits of the modern Cordilleras, and very much of the details of their fundamental structure.

This was the beginning of the Cambrian Age. This was the extent and configuration of the lands when Cambrian sediments began to accumulate. These were the continental nuclei. The student will particularly notice that the continent of the beginning of Cambrian time was formed of Eozoic rocks. In that sense we may speak of it as the Eozoic continent.

It will be observed that the mapping of an ancient continent is much more than the mapping of the rock exposures of the corresponding age. If it were not, we might get a map of America at the beginning of any Age — the Carboniferous, for instance, by simply taking a geological map and coloring out all the Carboniferous and newer formations. But, to illustrate the uncertainty of such a method, let us suppose the upheaval of the Seaboard Eozoic took place after the Carboniferous Age, instead of at the end of the Eozoic. Such may easily have been the fact, especially as we know that was the epoch of Appalachian upheaval. The Appalachian Eozoic, therefore, should not appear on a map of the continent as it was at the beginning of the Carboniferous Age. There are geologists who would leave it off; but we think evidences exist that a great mass of Eozoic dry land stretched along the place of the present Atlantic seaboard, as represented on our chart, Fig. 297. As it will be necessary hereafter to speak of that land, we may at once designate it the Seaboard Land.

4. *Cambrian Rocks and Minerals.* By reference to the Table at the beginning of this Section it will be seen that the best known formation at and near the base of the Cambrian is the Potsdam Sandstone. This formation varies from friable to hard. It is generally somewhat coarse-grained, and free from argillaceous matter. Its color is grayish, or reddish, or mottled. The student should fix his attention upon this fundamental member of the Cambrian. It may be well to refer here to the Cycle of Sedimentation, explained on page 268. Often the Potsdam Sandstone rests directly on the Huronian or Laurentian. This relation is well shown in Fig. 107, where *S* is the Potsdam Sandstone; as also in Fig. 55, where *P* is the sandstone and *E* the underlying Eozoic. Fig. 38 illustrates the same; and this may be considered a section across the Adirondac region, *c* being the Potsdam Sandstone resting on the eroded stumps of the Eozoic gneisses and schists. Tracing the Potsdam Sandstone thence along the border of the Cambrian lying nearest the Eozoic, we find it in Wisconsin lying horizontally upon the ruggedly eroded surface of the Huronian. Fig. 298 is a very interesting illustration of the contact between the two. The Potsdam Sandstone lines the south shore of Lake Superior from the Sault to Keweenaw Point, and forms the celebrated scenery of the "Pictured

Rocks. On the west of Keweenaw Point most of the sandstone belongs to the Keweenian; but at Bayfield and at the Apostles' Islands the horizontal sandstone is Potsdam. The formation outcrops in the Black Hills of Dakota, surrounding the Eozoic nucleus. It is extensively developed along the Appalachian chain — the slates and sandstones attaining a thickness of 3,300 feet. In East Tennessee sandstones and shales several thousand feet thick are described by Safford — Chilhowee sandstone resting on Ocoee conglomerates, sandstones, and micacous, talcose, and chloritic slates. These enter into the Unaka Range, as shown in Fig. 33. The formation is known in the Big Horn Mountains, at the head of Powder River, along the Wahsatch, Teton, Madison, and Gallatin Ranges, also in Central Nevada and other regions of the Far West. The face of a Potsdam cliff on the Upper Mississippi is shown in Fig. 30.

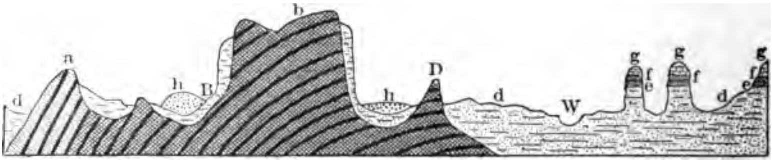


FIG. 298 — SECTION IN SAUK COUNTY, WISCONSIN, SHOWING THE CONTACT BETWEEN THE POTSDAM SANDSTONE AND THE HURONIAN QUARTZITE. (R. D. Irving.) *B*, Baraboo River; *D*, Devil's Nose; *W*, Wisconsin River, separating Sauk from Columbia County; *a*, North Quartzite Range; *b*, South Quartzite Range; *d*, Potsdam Sandstone; *e*, *f*, upper portions of Potsdam Sandstone; *g*, Lower Magnesian Limestone; *h*, Drift. This is the Quartzite referred to, page 363.

The Canadian Group represents the approach of limestone-making conditions, but not their full advent. The strata of the East range from a calcareous sandstone below, to an arenaceous limestone above — the Chazy. These, in the Montreal basin, undergo a large development, and constitute an argillo-calcareous group (the "Quebec") of local importance. In the Mississippi valley, the "Lower Magnesian Limestone" holds position here. This is a buffish, coarse, or granular limestone, well developed in southern Missouri and along the Mississippi north of Dubuque. A common appearance presented by these two formations in the banks of the Mississippi is shown in Fig. 299. The usual erosion of the underlying sandstone is shown in Fig. 26, which also shows oblique laminations — more clearly shown in Fig. 195.

In the valley of the Upper Mississippi, the Lower Magnesian Limestone is succeeded by a whitish friable sandstone known as the St. Peters Sandstone, which attains, in places, a thickness of 200 feet. It is sometimes regarded as a western representative of the Chazy formation. In truth, however, the Calciferous, Quebec, and Chazy, all together, occupy the interval held by the Lower Magnesian Limestone and St. Peters Sandstone at the West.

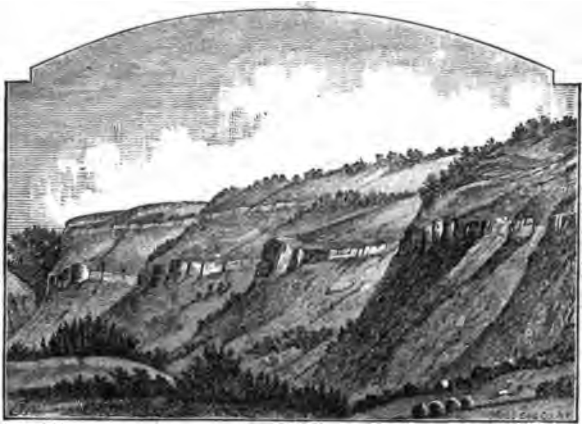


FIG. 299.—BLUFFS ON THE UPPER MISSISSIPPI NEAR PRAIRIE DU CHIEN. CAMBRIAN ROCKS. The Lower Ledge is Potsdam Sandstone, and the Upper, the Magnesian Limestone. (D. D. Owen.)

The central and characteristic mass of the next Group is calcareous — the great Trenton Limestone, named from Trenton Falls on the East Canada Creek in Central New York. It stretches along the middle of the Cambrian belt of strata as formerly traced, into the Upper Mississippi region, and northward past Winnipeg. The Galena Limestone of Illinois, Wisconsin, and Iowa is the upper part of the Trenton. Its thickness in the great Montreal basin is 800 feet; in the Mississippi valley, 100 to 200 feet; in the Appalachians it amounts to 2,000 feet. The

Cincinnati or Hudson River formation is a calcareo-argillaceous continuation of the Trenton.

Other regions where the Trenton and Cincinnati limestones are favorably exposed are Watertown, N. Y., in the banks of the Black River; the north shore of the Manitoulin Islands; the west shores of Green Bay and Little Bay de Noquet; southwestern Wisconsin and northwestern Illinois, and some parts of eastern Pennsylvania. The entire Cambrian strata of Nevada are reported by Hague 7,000 feet thick, and include, from below, the Prospect Mountain Quartzite and Limestone, the Secret Cañon Shale, the Hamburg Limestone, and the Hamburg Shale. The Pogonip Limestone, next in order, probably embraces the Quebec and Trenton formations. The Cambrian strata of the Wahsatch region are reported by King 12,000 feet thick.

5. *Erosion Features.* The weathering of the Cambrian rocks in Wisconsin and Minnesota has resulted in many remarkable forms. Figs. 30 and 32 have been cited. In Fig. 300 the "Hornets' Nest," the underlying sandstone, as in other cases, has worn away, leaving the Magnesian Limestone overhanging. In other cases enormous towers are left standing in the midst of a plain, showing how extensively formations have been swept away. Fig. 301 is an example of this kind in Dakota county, Minnesota. Here the isolated

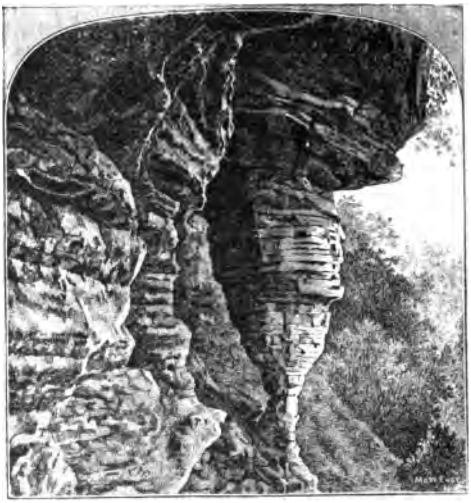


FIG. 300.—THE "HORNETS' NEST," WISCONSIN. EROSION OF CAMBRIAN ROCKS. (Chamberlin)

column is over 19 feet high above the base, which is itself 25½ feet high, making the whole *outlier* 44 feet 7 inches above the sandy plain. Much picturesque scenery results from erosion of the Cambrian rocks. The "Pictured Rocks" of Lake Superior are in the Potsdam Sandstone. The "Dalles" of the Wisconsin, Fig. 29, are in the same formation. The "Great Chasm of the Au Sable" in northern New York is cut in the Potsdam. The Trenton Limestone is the occasion of numberless waterfalls, some of which, like Trenton, Glenn's and Minnehaha, have become classic. The "High Falls" of the Hudson at Lucerne are partly in the Potsdam Sandstone.

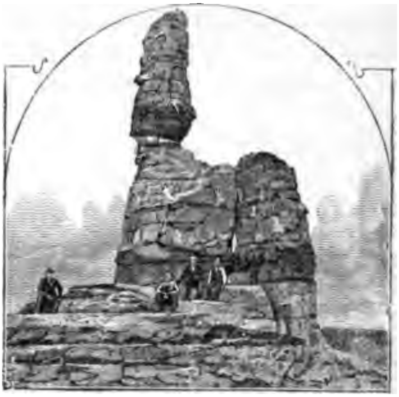


FIG. 301.—"CASTLE ROCK," MINNESOTA. OUTLIER OF CAMBRIAN ROCKS. (Photograph.)

The examination of a section along the Mississippi River, somewhat like that in Fig. 302, shows that the Cambrian sediments were deposited on a deeply eroded surface of Huronian rocks, constituting what has been explained as a break (page 263). Erosions take place above sea level or a little below it. This Huronian surface seems, therefore, to have been dry land for a long period, after its upheaval, and before the epoch of the Potsdam Sandstone. During that interval, sediments were accumu-

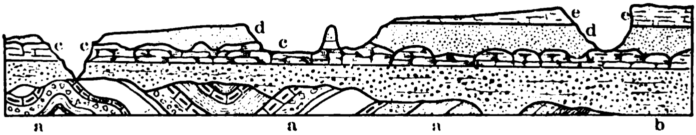


FIG. 302.—GENERALIZED SECTION ALONG THE VALLEY OF THE UPPER MISSISSIPPI. CAMBRIAN ROCKS. *a*, Eozoic rocks. *b*, Potsdam Sandstone. *c*. Lower Magnesian Limestone. *d*, St. Peter's Sandstone. *e*, Trenton Limestone.

lating in other regions. That is, before the Potsdam epoch, and after the close of the Eozoic, some other formation unrepresented in the Northwest — unless the Keweenian fill the gap — was produced. This intervening formation is found at several points in the East, and is known as the Acadian Stage, consisting chiefly of slates, so far as known. The Acadian Stage is recognized also in the Wahsatch and Great Basin regions. The Potsdam, therefore, was not laid down over the Northwest until after a subsidence. In other words, a map of the continent at the beginning of Cambrian time must show more land than the present exposures of Eozoic rocks.

A similar history appears to have been undergone in the broad Cordilleran region which we have mapped as land at the beginning of Cambrian time. After undergoing vast sub-aerial erosions, during which marine sediments were accumulating elsewhere, a great subsidence took place, and the region became an archipelago. This was before the opening of Cambrian time, for we find the oldest Cambrian sediments deposited horizontally in the deep valleys of that ancient wasted surface. The entire Cambrian series was built up in horizontal sheets, and the Cordilleran mountain slopes were slowly buried. The same order of events continued through the Silurian, Devonian, and Carboniferous ages. The horizontal Palæozoic strata abut against the ancient slopes; and in one case at least, according to King, they rise 30,000 feet along a mountain acclivity.

The "Cincinnati Swell," so called, is an upswelling of the strata causing dips east and west from Cincinnati, as shown in Fig. 303. The oldest rocks are exposed in the bed of the Ohio River and in the amphitheatre of hills surrounding the city. Following the river downward or upward, we reach outcrops of formations successively higher in the series, and soon rise to the Coal Measures. Underneath the Trenton Limestone, beneath the bed of the river, lies the Potsdam Sandstone, which has been actually reached in boring an artesian well at Columbus. The hills about the city are formed of the thin-bedded limestones and shales of the Cincinnati Group. In central Tennessee, rocks of the same age are similarly brought to light by erosion (see Fig. 33), but with less of a swell in the strata. The fossiliferous limestones, clays, and shales of the suburbs of Cincinnati are reproduced in the hill slopes and river bluffs of Nashville.

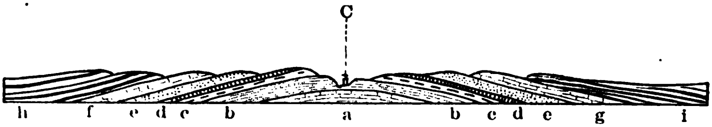


FIG. 303.—SECTION ACROSS THE CINCINNATI SWELL. *C*, Cincinnati. *a*, *b*, Cambrian; *c*, Silurian; *d*, Devonian; *e*, Waverly; *f*, Carboniferous Limestone; *g*, Equivalent of Carboniferous Limestone on the easterly side; *h*, Illinois Coal Field; *i*, Appalachian Coal Field.

6. *Organic Remains.* The Cambrian rocks generally are well stocked with relics of the life of the Age. For the Potsdam Sandstone, the Upper Mississippi valley is the best collecting ground. For the Trenton and Cincinnati formations, northwestern Illinois, southwestern Wisconsin, northeastern Iowa, and southeastern Minnesota are prolific regions. None, however, have yielded a greater abundance of good fossils than the Cincinnati and Nashville areas. The former includes Richmond and Madison, Ind., and Lexington and Frankfort, Ky.; the latter, Lebanon, Columbia, Franklin, and Murfreesboro. At all the points named, the surface of the ground and the banks of the streams are strewn with fossil remains surprisingly well preserved. Scarcely less abundant or excellent are the fossils found along the western shores of Green Bay, and the north shore of Drummond's Island, in Lake Huron. Along the Black River, in New York, at Trenton Falls, and in Centre county, Pennsylvania, are also rich deposits. In central Nevada, the Pogonip and Hamburg ridges are found fruitful in fossils.

The study of these remains shows that with the dawn of the Palæozoic Æon, life was exceedingly abundant in the sea; but neither land animals nor plants are indicated, save some probable tree trunks from the Cincinnati region. In respect to rank, these animals ranged over all the classes of invertebrates. The Trilobites, already sketched (page 323), were highest in rank, and most conspicuous in the Primordial Period, and continued throughout. Cephalopods of the type of *Orthoceras* were perhaps equal in importance, and were certainly dominant in prowess. Of these a sketch has also been given (page 326). It is noteworthy that forms indicating much complication and differentiation in structure come from a horizon as low as the Calciferous, implying, perhaps, that simpler forms, still undiscovered, had been in existence during periods still more remote. Among humbler forms were Crinoids, beautiful creatures which rooted themselves in the submarine soil, and grew like tiny animated palms. These have also been sketched (page 324). But besides these types were others which played important roles in the plan of life and the processes of sedimentation. Coral makers of the type of Polyps were not conspicuous, except *Faristella* and *Streptelasma*, Figs. 123, 4, but coral makers of the type of Bryozoa were extremely abundant during the Trenton Period. Individual animals were extremely small, but they combined in large numbers, and secreted coral masses from one to eight inches in diameter. Brachiopods may be particularly mentioned as beginning their geological history in forms related to *Lingula*, *Strophomena*, and *Orthis biforata*. These have been already described and illustrated (Studies XXXIII and XXXIV). *Zygospira modesta* (Fig. 178), *Orthis subquadrata* (Figs. 166, 171), *Strophomena alternata* (Figs. 191, 192), and *Orthis biforata* (Fig. 163), are widespread and characteristic species. The particular features of Palæontology, however interesting or important, must here be passed over, to be taken up in a more advanced course.

The exuberance of marine life at an age so remote that, aside from Eozoön, by some denied, it seems to represent the very first act in life's drama, is a great fact which may well astonish and prompt to speculation. We must remember that remoteness reduces the perspective of the Cambrian to a seeming point of time, while it was undoubtedly measured by hundreds of thousands of years. We may bear in mind, also, that the wonderful diversification of Cambrian types, even from the beginning, may possibly have been progressing during that long Huronian Æon all traces of whose organization have been obliterated by the physical vicissitudes of our planet.

§ 4. The Silurian System ("Upper Silurian" of Authors).

1. *Divisions, Subdivisions, and Terms.*

- III. **Lower Helderberg Group** (7).
- II. **Salina Group** (6).
- I. **Niagara Group** (5).
  - 3. NIAGARA STAGE (5*c*). (2) Niagara Limestone; (1) Niagara Shale.
  - 2. CLINTON STAGE (5*b*).
  - 1. MEDINA STAGE (5*a*). (2) Medina Sandstone; (1) Oneida Conglomerate.

The Silurian System, named from *Silures*, the ancient people of Wales, was intended by Murchison to embrace all the fossiliferous rocks under the Devonian. The progress of discovery having extended downward our knowledge of such rocks, Sedgwick bestowed the name Cambrian on those which he regarded as underlying the Silurian, as originally known to Murchison; while the latter designated them Lower Silurian. Aside from other considerations, convenience requires a single designation for every group important enough to stand in the relation of a "System." Hence, with good reason, the National Survey has proposed the use of these terms as here employed.

The other terms employed in the above table are all of New York origin, and require little explanation. The Helderberg Mountains are in eastern New York, south of Albany. The Salina Group, named from its productiveness in salt, was originally the "Onondaga Salt Group," from its supply of brines in Onondaga county.

2. *Geographical Extension.* If we start from the Niagara River, which gives its name to the most important mass of the Silurian, lithologically speaking, we find this system stretching eastward in a broad belt through central New York to the Hudson River. Northward, it spreads to Lake Ontario; and southward, it stretches along the valley of the Hudson, bending in southeastern New York conformably with the trend of the Appalachians, which it follows as far as Georgia. Westward and

northwestward from the Niagara River, the Silurian belt stretches across Ontario to the headland separating Georgian Bay from Lake Huron. It forms the southern and principal part of the Manitoulin Islands, and borders the northern and western shores of Lake Michigan, forming the cape which divides Green Bay from Lake Michigan, and spreading southward beyond Chicago. Green Bay is thus the counterpart of Georgian Bay. Each bay is separated from its lake by a promontory of Niagara Limestone. A belt of importance surrounds the Cambrian area whose centre is at Cincinnati, and this extends northward to include Sandusky. Other Silurian strata are exposed around the Nashville Cambrian, especially on the west. Silurian rocks are known in Maine, and other parts of New England; but in some parts, and in regions farther toward the northeast, they have not yet been completely discriminated from the Cambrian and Devonian.

Throughout the whole extent of the Silurian, the Niagara Limestone is the great and salient feature. A little acquaintance with the physical features of the country will enable one to trace this formation by means of the quarries, ledges, and escarpments which everywhere accompany it; and when the place of this limestone is known, it may be understood that the higher groups lie on the side *away from* the older formations — that is, Cambrian and Eozoic.

3. *The Continent at the Beginning of Silurian Time.* During the Cambrian Age there occurred in northeastern America a succession of uplifts of the sea bottom; and in consequence new belts of territory were added to the Great Northern Land represented in Fig. 297. Speaking generally, the areas on the geological map shown as Cambrian rose above sea level during the Cambrian Age, and at its close. As in the East, later geological erosions have removed some portions of the original Cambrian covering the Eozoic nuclei of the land, we represent the land at the *beginning* of Silurian time as somewhat more extended than the Eozoic and Cambrian surfaces on the Geological Map.

In the Cordilleran region, on the contrary, the close of the Eozoic was marked by a subsidence of this entire continental limb, for the Cambrian sediments are laid down over the whole of the ancient eroded Eozoic surface, with numerous island-like exceptions. The subsidence continued *through* the Cambrian, but was greatest toward the west, where the Cambrian strata are now thickest. The portion of the land which supplied the sediments was over western Nevada and the extreme eastern belt of California. The great Cambrian ocean east of the Nevada land was interrupted only by the rugged peaks of the ancient sunken continent of the earlier Æon, some of which are shown on the map, Fig. 304. Similarly the great Seaboard Land appears to have begun a process of subsidence, through which it was overlapped to an unknown extent by Cambrian and later deposits.

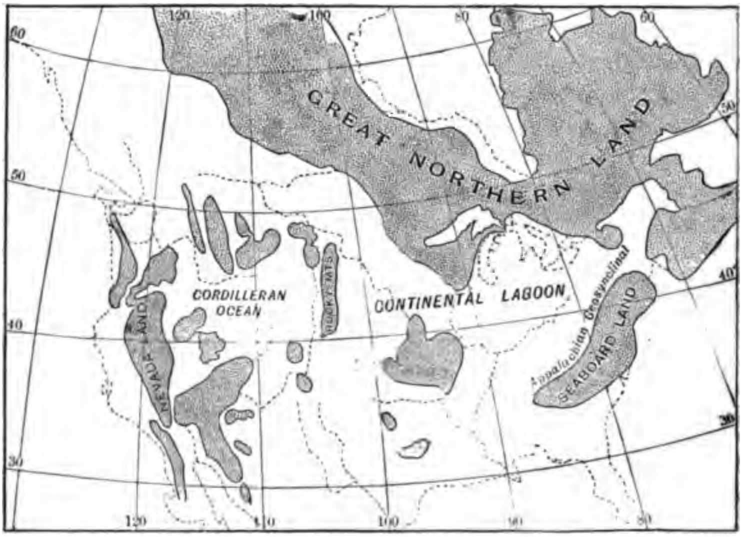


Fig. 304.—Map of North America at the Beginning of the Silurian Age.

In consequence of Cambrian elevations in the Northern Land and Cambrian subsidences in the others, the Northern Land is now enlarged on all its borders, and has a belt of Cambrian sediments encircling it on the southern side, and probably to a limited extent around the Hudson's Bay border also. But the Seaboard and Cordilleran Lands having subsided at and since the close of Eozoic time, neither presents as large an area as in the map, Fig. 297. The Cordilleran Land, in fact, was reduced to an archipelago at the beginning of the Cambrian Age, and remained such, with even diminishing land areas, to the beginning of the Silurian Age, as represented in map, Fig. 304.

It is scarcely necessary to say that these maps are merely approximate and suggestive. Where land areas subside they carry out of sight the visible evidences of subsidence; and where they rise it is not always possible to ascertain whether elevation attained was greater or less than the elevation existing at the present time. Movements *of the kind* here indicated, however, took place; and what is shown by these tentative maps of the growing continent imparts general conceptions which are correct.

4. *Silurian Rocks and Minerals.* The Oneida Conglomerate at the bottom properly exemplifies the beginning of a new cycle of sedimentation (see page 268); and the progress of it is shown in the succession of the Medina Sandstone. But these two formations cannot be traced westward beyond middle Ontario. The West was too remote from the source of the sediments, which was probably in the decaying Seaboard Land; and coarse materials are replaced by finer, mostly calcareous deposits. The argillo-calcareous strata of the Clinton Stage are seen, however, on the Manitoulin Islands, and farther west in Wisconsin and Indiana, as well as in Ohio, Tennessee, and other regions — always not far removed from outcrops of Niagara Limestone. The Medina Sandstone is a hard, gritty, even-bedded, reddish, whitish, or mottled rock, quite extensively quarried for building purposes, especially in the vicinity of Lockport, N. Y. The Clinton formation embraces, westward, thick-bedded, fine-textured, aluminous limestones, presenting a beautiful appearance, but too retentive of moisture for outdoor architecture. By hard freezing the blocks are shivered to fragments. It includes important beds of lenticular iron ore in the lower part, from the Genesee River eastward, and forms valuable deposits in Wisconsin, eastern Tennessee, and Nova Scotia.

The Niagara Limestone is generally a light or dark gray, heavy-bedded rock, having a semicrystalline texture. On Drummond's Island, and all around the northern and western shore of Lake Michigan, to Chicago, the principal beds are quite crystalline, but abound in small crystal-lined cavities, which impair its value as a building stone. It is, however, extensively quarried for building and for limemaking, a portion of the formation being free from the defect just mentioned. Beds especially adapted for building are found in western New York and at Joliet, Lamont, and thereabouts in Illinois. The celebrated "Athens Marble," so called, is quarried near Joliet and Lamont, and was before the "great fire" a favorite building material in Chicago. It remains in excellent repute at the present time. Niagara limestone is extensively quarried at Huntington, Ind. In Chicago and that vicinity some strata of the Niagara limestone are quite saturated with petroleum, and many fruitless expenditures have been incurred in the attempt to collect this fluid in quantities of commercial importance. (But see Part I, Study XXVII.) It is said the first artesian wells of Chicago resulted from the ventures of oil seekers; though it is certain that geologists had already asserted the practicability of procuring water, and the impossibility of getting supplies of oil.

The Salina Group consists, in Central New York, of tender, clayey marlites and fragile clayey sandstones of red, gray, greenish, yellowish, or mottled colors, constituting the lower half; and above these, calcareous marlites and impure drab-colored limestone, containing beds of gypsum, followed by hydraulic limestone. A vein or bed of dark-green serpentine occurs in the formation, in the city of Syracuse, on James street, and a few rods to the south. The great feature of this group is the salt and gypsum which it affords. (For geology of Salt and Gypsum see Part I, Study XXVI.) Rock salt is now known to have a wide distribution through the Salina in southwestern New York, Ontario, eastern Michigan, and western Michigan. At Marine City, on the River St. Clair, it is found over 115 feet thick, at a depth of 1,633 feet to 1,748 feet from the surface; and an enormous manufacture of salt has been established by first dissolving the rock salt by forcing down clear water from the St. Clair River, and afterward evaporating the brine by means of steam pipes. Rock salt is also found of great thickness at Manistee, Ludington, and Muskegon, on the west side of the state. Near Goderich, Ontario, 126 feet of rock salt are found in 520 feet of strata, down to a depth of 1,517 feet. In Ontario rock salt is obtained at a depth somewhat over a thousand feet, at various points stretching from Kincardine on Lake Huron, on the north, to Dawn, near Lake St. Clair, on the south. In Western New York rock salt has been found at depths generally a little over 1,000 feet at various localities in Wyoming, Livingston, Ontario, Yates, Seneca, and Cayuga counties — that is, from the centre of Wyoming county eastward to Aurora, on Cayuga Lake. The salt bed ranges from 70 to 85 feet in thickness. No rock salt has been found by boring at Syracuse to the depth of 1,969 feet.

Gypsum, also, is quarried extensively in Cayuga county, New York. It outcrops on the lake shore at Little Point au Chêne, a few miles west of Mackinac. The gypsum of Sandusky Bay, of Cayuga, and Ontario, is of the same age.

The Helderberg Group — originally Lower Helderberg — consists of a series of shales and shaly limestones and proper limestones, developed especially in the Helderberg Mountains, but extending westward, with diminished thickness, to Syracuse, Buffalo, and western Ohio. It is known also in Indiana, southern Illinois, and other Western States. The formation extends southward along the Appalachians; and is known in Massachusetts, New Hampshire, Maine, Nova Scotia, and New Brunswick. It is famous for its production of hydraulic limestone, which supplies the Buffalo Cement Works and numerous other establishments in New York and Ohio. The formation also contains gypsum.

5. *Erosion Features.* Beginning again at the Niagara River, near its mouth, a high escarpment is found, which runs eastward parallel with the shore of Lake Ontario. At Lockport the Erie Canal crosses it, giving occasion for the "locks" which give

name to the city. At Rochester it is crossed by the Genesee River at the "Falls." The great gorge of the Niagara River is cut back through this escarpment for about seven miles. A fine section of the Silurian strata may be seen along the walls of this gorge, and they are shown in diagram in Fig. 305. This diagram mostly explains itself. The lower part is supposed to be joined on at the right hand extremity of the upper part. The student will be able to trace the surface of the water from Lake Ontario over the Falls and Lake Erie to Lake Michigan and Chicago. At Cleveland is seen the high bluff on the south shore of Lake Erie; and here is a break in the diagram, in consequence of changes in the direction of the section, and in the direction of the dip of the strata. Other features of the diagram will be referred to in connection with post-glacial history.

The position of the Falls, now 150 feet high, indicates to what extent the gorge has been excavated back from the escarpment. We see the water precipitated perpendicularly over the brink of the thick-bedded Niagara Limestone. The reaction against the underlying shale results in its erosion. The limestone thus undermined breaks off by piecemeal, and thus the Falls recede at the rate of about three feet a year. Within thirty or forty years the aspect of the Falls has changed materially. Within the memory of a generation, "Table Rock," as shown in the cut, Fig. 306, was a great curiosity and point of interest at the Falls on the Canadian side. But it has fallen into the abyss. Great encroachments have also been made on Goat Island.

6. *Organic Remains.* The life of the Silurian was, in general, a continuation of the types of the Cambrian. The Silurian genera and species of the Cambrian families showed the progress of those changes which express slow organic advance. The forms were less archaic, and less removed from the aspects of the modern world. Corals and Crinoids became more abundant. The *Favosites* family was developed under multiplied generic and specific forms. Some of these are illustrated in Figs. 144, 145, 146, 148, and 149. Rugose corals also underwent important expansion, but their fullest development was yet future. Cham-

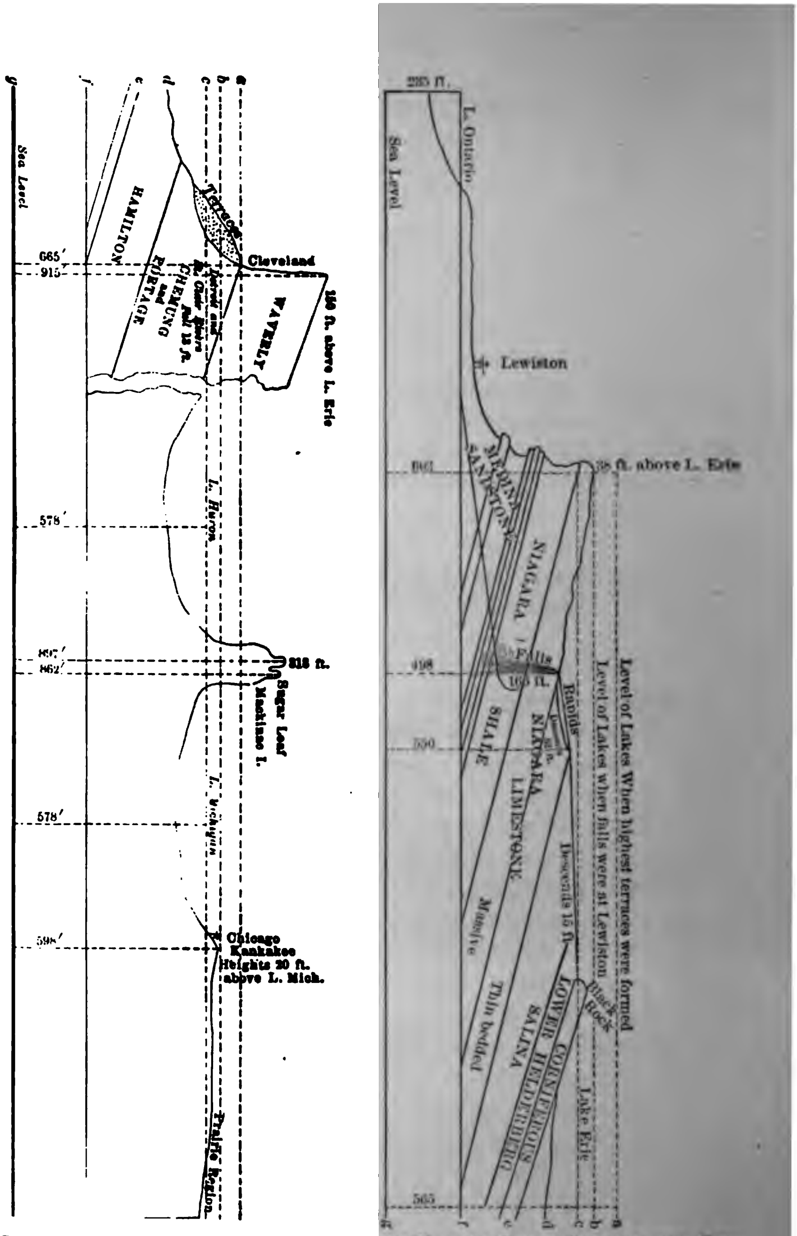


FIG. 305.—DIAGRAM OF THE STRATA ALONG THE NIAGARA GORGE, SHOWING THE GEOLOGICAL POSITION OF NIAGARA FALLS AND THE ANCIENT LEVELS OF THE GREAT LAKES.

bered Molluscs diminished in numbers and in size; but the coiled genera became rather more abundant. Other classes of Molluscs increased in relative numbers. Trilobites were shrunken in numbers and in bulk. One of them is represented in Figs. 229 and 230, and is to be contrasted with the Cambrian Trilobite, Fig. 228. The Silurian, however, witnessed the introduction of a type entirely new. This was the important type of Vertebrates. According to the established method of succession, they were aquatic breathers; they were low in the Stem or Sub-Kingdom, and were "comprehensive" forms, like all primitive types. Some description of them has been given at pages 231–235. Further palæontological details must be passed by.

FIG. 306.—TABLE ROCK AT NIAGARA FALLS, AS IT WAS.

§ 5. The Devonian System.

1. *Divisions, Subdivisions, and Terms.*

V. **Catskill Group** (12), Catskill Red Sandstone [may be Carboniferous].
IV. **Chemung Group** (11).
  2. CHEMUNG STAGE (11*b*), } Erie Shale of Ohio,
  1. PORTAGE STAGE (11*a*), }
III. **Hamilton Group** (10).
  3. GENESEE STAGE (10*c*), Tennessee Black Shale. Huron Shale of Ohio.

} Huron Group of Michigan.

  2. HAMILTON STAGE (10*b*).
  1. MARCELLUS STAGE (10*a*). Marcellus Black Shale.
- II. **Corniferous Group** (9).
  3. CORNIFEROUS and ONONDAGA LIMESTONES (9*c*) (= "Upper Helderberg Group").
  2. SCHOHARIE GRIT (9*b*).
  1. CAUDA-GALLI GRIT (9*a*).
- I. **Oriskany Group** (8). Oriskany Sandstone.

By some the Oriskany is regarded rather as Silurian than Devonian. Palæontologically it has some affinities with Niagara forms, and also some Devonian relations. The fauna is transitional, as it should be. Lithologically, however, the formation is plainly the beginning of a new geological era.

The Catskill, placed here at the top of the Devonian, in deference to prevailing usage, may very likely prove to be the basal group of the Carboniferous System. It is commonly regarded as representing the Old Red Sandstone of Scotland, which is Devonian, according to most geologists. Some British geologists, on the contrary, regard the upper beds of the Old Red as Carboniferous; and this is strongly evinced at Dura Den and Arran. If they are so, and the Catskill finds its equivalents in them — as the fossils indicate — the Catskill becomes Carboniferous, and holds exactly the horizon of the Waverly (as qualified by the late Ohio survey) and Marshall of the West, which, on independent palæontological grounds, may perhaps be parallelized with the Catskill.

The geographical terms here employed are derived from localities in the State of New York. "Corniferous" comes from *cornu*, a horn, in allusion to the amount of "hornstone" contained; or, perhaps, in allusion to the horn-shaped cup corals which abound. "Cauda-galli," signifying cock's tail, refers to a peculiar fucoid which the formation contains.

2. *Distribution and Lithological Features.* The Oriskany Sandstone is mostly a purely silicious, friable, rough-looking rock, but is a somewhat inconspicuous formation, although it accompanies the other Devonian strata along the Appalachians, and into Ohio, Indiana, and Missouri, and attains a thickness of 250 to

300 feet in southern Illinois. A formation commonly known throughout the West as the "Black Shale" — a black, bituminous, argillaceous shale — is a very persistent and characteristic part of the Hamilton Group. Without much doubt, it is the equivalent of the Genesee Shale of New York. The Marcellus Shale is a very similar formation, with some interstratified limestones, and extends as far west as the Detroit River, and perhaps into Ohio. The rocks of the Chemung Group are a bulky and conspicuous mass of greenish, yellowish, and buffish shaly sandstones and variously colored shales, becoming in Ohio and Michigan essentially a series of clays and argillaceous shales. They represent, therefore, a continuation of the shaly conditions begun with the Genesee Shale, and constitute with that formation a stratigraphical series which is physically a unit, and, therefore, in Michigan was designated the "Huron Group." The Chemung rocks (including the Portage) have a very large development in southern New York and Pennsylvania, but are deficient south and west of the Ohio.

The most conspicuous and most persistent lithological feature of the Devonian is the great central calcareous mass. This is made up primarily of the united Onondaga and Corniferous limestones; but in Ohio, Michigan, and other western states, as far as Iowa, the Hamilton formation, predominantly argillaceous in New York and Ontario, becomes predominantly calcareous; and since the Marcellus Shale is generally wanting in the West, the Hamilton and Corniferous limestones unite in one great calcareous formation. In Ohio and Indiana the formations between the Corniferous and Niagara limestones are also wanting; so that the Hamilton, Corniferous, and Niagara limestones are all brought together, forming what the older writers termed the "Cliff Limestone" (Fig. 307). The separation of all these is now easily effected by means of their fossils.

The great limestone mass of the Devonian forms a conspicuous feature in the landscape, traceable by a line of quarries and ledges all the way from central New York to Iowa. Its position is not far from the centre of the belt marked as Devonian on the

Geological Map; but west of Ohio the limestones make up the principal part of this belt.

The economical products of the Corniferous are materials for quicklime and for building purposes. For the latter it is much employed in central and western New York, and in northern Ohio and Ontario. Large accumulations of petroleum are found in the crevices and caverns of the Hamilton Limestone in Ontario. The Corniferous Limestone is very often found saturated with dark petroleum, but no permanent supplies of importance have been obtained from it. The most considerable yields have been found at Tilsonburg, Ont., and Terre Haute, Ind. Petroleum also accumulates abundantly in the Chemung sandstones of southern New York and western Pennsylvania. (See Part I, Study XXIX.) For building purposes these sandstones possess, generally, insufficient coherence. Beds probably the equivalent of the Chemung constitute the "Kidney Iron Formation" of Branch County, Michigan.

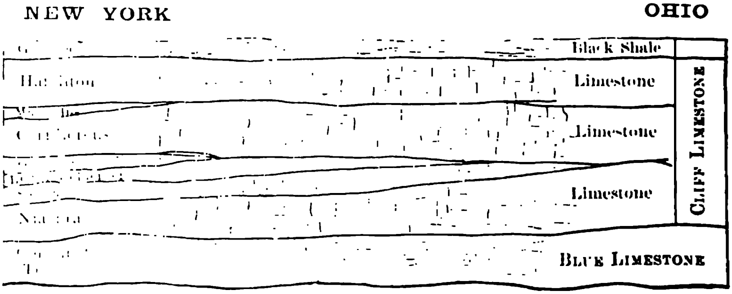


FIG. 307.—CONSTITUTION OF THE "CLIFF LIMESTONE" OF OHIO.

3. *Erosion Features.* The Corniferous Limestone has been the theatre of great erosion along the course of certain rivers, and around the shores of the Great Lakes. In central New York many deep valleys like that of Onondaga Creek, south of Syracuse, have been excavated in the Corniferous and Onondaga formations. In the vicinity of the Straits of Mackinac the Corniferous limestone has been eroded on a grand scale. A lofty

barrier once separating the basins of Lake Huron and Lake Michigan has been cut through. In the midst of the passage rises the Island of Mackinac to the height of 350 feet. On three sides the island is bounded by precipitous walls about 150 feet high. On the west, on the Upper Peninsula of Michigan, is a headland known as Rabbit's Back, which is the continuation of the limestone of Mackinac Island. On the south, the main land of the Lower Peninsula presents a similar but less elevated promontory, and the exposure of the formation stretches toward the east and the west. The whole island is manifestly a relic and memorial of the destructive power of the elements. The waves have beaten its precipitous walls, and wasted them away at unequal rates. Fissures, purgatories, and caverns have been opened at different stages in the height of the waters. In one place, a veritable natural bridge stands swung at an elevation too high for the eroding agent to reach (Fig. 309). On the main plateau of the island rises Sugar Loaf (Fig. 310) 134 feet above the plain. The pinnacle of the island was the site of Old Fort Holmes. (Compare also Fig. 305.)

The axis of Lake Huron crosses diagonally the trend of the Corniferous limestones. The lake shores present many

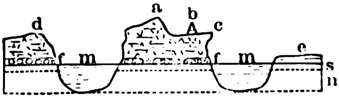


Fig. 308.

Section Southeast and Northwest through Mackinac Island. *a*, Old Fort Holmes; *b*, Sugar Loaf; *c*, Robin-Folly; *d*, Rabbit's Back, on the Upper Peninsula; *e*, Round Island; *f*, Conglomeritic stratum; *m*, surface of the lake.

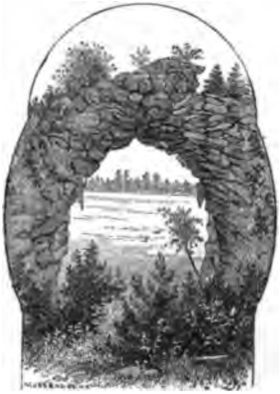


Fig. 309.

"Arched Rock," Mackinac Island. Corniferous Limestone.

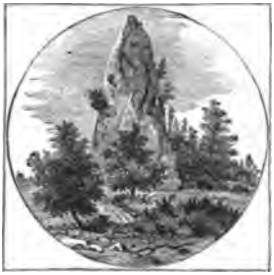


Fig. 310.

"Sugar Loaf," Mackinac Island. Corniferous Limestone.

cases of bold erosion. Off Thunder Bay Island, in fair weather, one may look down a subaqueous cliff ninety or one hundred feet, into a dark abyss of water. Near Louisville was once a fall in the Ohio River, over a ledge of Corniferous limestone. The retreat of these "Falls" has reduced them to mere rapids; but they still present a fine example of erosion. Other instructive examples may be seen on the Mississippi River at Rock Island, and at the head of Little Traverse Bay of Lake Michigan.

4. *Organic Remains.* In the invertebrate realm we find the coral type exceedingly augmented during the Devonian. Great coral reefs appear to have been built up somewhat as in modern times. One of these is exposed at the "Falls of the Ohio." This has been a favorite collecting ground for more than a generation. Here abound corals of the types of the Rugosa and Tabulata, the study of which was explained in Part I, Studies XXX–XXXII. A similar reef exists at the head of Little Traverse Bay, near Petoskey. Here the type of *Stromatoporidæ* undergoes a remarkable development; and this is repeated in the same formation on the opposite side of the state, at Thunder Bay, and the vicinity. *Stromatoporidæ* make up a large part of the reef-like masses forming the Hamilton limestone of these regions. This interesting type seems to have attained its culmination in the Hamilton and Corniferous periods. We have devoted some space to its exposition and illustration in the last chapter. See Figs. 223–7.

Examples of Devonian corals are shown in Figs. 130–143; also 147–158.

Some characteristic Devonian Brachiopods are seen in Figs. 161, 162, 165, 166, 168, 170, 172, 174, 177, 179, 180, 184.

Some characteristic Devonian Fishes are illustrated in Figs. 241–247.

A majority of the fossils furnished by the Drift of the northwestern states are of Devonian age.

§ 6. The Lower Carboniferous System.

1. *Divisions, Subdivisions, and Terms.*

II. **Carboniferous Limestone,** or **Mississippi River Group** (13). Mountain Limestone.

4. CHESTER STAGE (13*d*). (2) Kaskaskia, or Upper Archimedes Limestone; (1) Pentremital Limestone.
3. ST. LOUIS STAGE (13*c*). St. Louis Limestone. Part of Silicious Group, Tenn.
2. KEOKUK STAGE (13*b*). Keokuk Limestone. Part of Silicious Group, Tenn.
1. BURLINGTON STAGE (13*a*). Burlington Limestone (?)="Michigan Salt Group."

I. **Marshall,** or **Waverly Group** (12). "Kinderhook Group," of Ill.; "Yellow Sandstones," of Iowa; "Chouteau" and "Lithographic" Limestones, of Mo.; "Goniatite Limestone," of Rockford, Ind.; "Silicious Group" (lowest beds), Tenn. As before stated, the Group may be the western equivalent of the prior-named "Catskill."

The Lower Carboniferous Series is frequently designated "Sub-Carboniferous"; but as this term necessarily signifies "under the Carboniferous," it is etymologically inadmissible, since the Series is universally recognized as a part of the Carboniferous. The term Carboniferous signifies coal-bearing; in fact, however, the great coal-bearing strata in many parts of the world are Mesozoic, or even Cænozoic.

The numerous local designations of the lower Group originated in the fact that for years these rocks, in Ohio, Iowa, Missouri, and Michigan, were regarded as the western equivalent of the Chemung; until, in some regions, they were seen to be so clearly Carboniferous that more thorough examinations were instituted. During the discussion, the formation in each state — not yet known to be the same formation — received a local designation.

The great limestone formation of the Lower Carboniferous Series may appropriately be designated the Carboniferous Limestone, since in the whole Carboniferous System it is by far the most important and most persistent limestone mass. In the

United States, it underlies chiefly the great valley of the middle Mississippi; and hence the present writer once suggested for it the "Mississippi River Group." In many parts of Europe it enters into the formation of mountains, and is commonly known as the Mountain Limestone.

2. *Distribution and Lithological Features.* The Marshall, or Waverly Group, consists in Michigan and Ohio of rusty, or yellowish, mostly friable, sandstones, becoming, in the lower beds, grayish or bluish, and at bottom, decidedly argillaceous. Locally, some of the beds are quite calcareous and finely cemented. In Michigan, the formation outcrops at intervals in a broad belt passing through the central southern counties, and extending northwest into Ottawa county, and northeast to the lake shore (Point aux Barques), in Huron county. In Ohio it stretches from the lake shore, in the vicinity of Cleveland, southward across the state to Waverly and the Ohio River. In eastern Iowa the formation is yellowish or buffish, friable, and in the lower part, argillaceous. In Missouri it is mostly argillo-calcareous. In southern Illinois, Kentucky, and Tennessee, it is in part a dark, laminated, silicious shale.

Some of the purely arenaceous beds afford superior gritstones, of which the Berea (Ohio) and Huron (Mich.) grindstones are examples. They are equally in request for building and flagging purposes. The famous bluestone, or freestone, of Cleveland and vicinity, and regions southward to Waverly, belongs here. The fine Nova Scotia freestone is probably of the same age.

The Carboniferous Limestone Group is almost exclusively calcareous. The St. Louis member, however, is apt to be cherty, especially in Kentucky and Tennessee, where it forms the most characteristic part of the "Silicious Group" of Safford. This cherty limestone is spread out over a large area through central Kentucky, and thence into Tennessee. It forms the rugged "Knob Region" of those states. In Michigan, the limestone is of the St. Louis and Keokuk subdivisions; in southern Ohio it is the Chester and St. Louis. In Michigan, however, is a member of the series underneath the limestone, which is argillaceous, with thin intercalated calcareous sheets, and heavy, persistent beds of beautiful gypsum, quarried very extensively near Grand Rapids, and also on the opposite side of the state, near Tawas Bay, at Alabaster. This is the "Michigan Salt Group." It is probably of the same age as the gypsum beds of New Brunswick, which, like the Michigan gypsum, belong to the upper group of the Lower Carboniferous.

The succession and conformability of the Lower Carboniferous strata are shown in the instructive bluff at Burlington, Iowa, a section of which is shown in Fig. 311. In spite of the complete conformability of the upper and lower strata, the distinctness of the two groups is evinced by the strong contrast in the organic remains.

Limestones of Carboniferous age occur at many points throughout the remote West; but in many cases they belong to the Upper Carboniferous; in other cases, their precise age has not been ascertained. Limestones of the Lower Carboniferous have been identified in the Elk Mountains of western Colorado; the Wind River Mountains of Wyoming; at Old Baldy, Montana, near Virginia City (Chester Limestone); at Fort Hall, Idaho (St. Louis Limestone); in the Wahsatch and Oquirrh ranges, Utah (St. Louis Limestone), and in the Eureka district of Nevada, where the Diamond Peak Quartzite is 3,000 feet thick. Probably some of the western exposures embrace strata of the Marshall Group. Carboniferous limestone occurs, also,

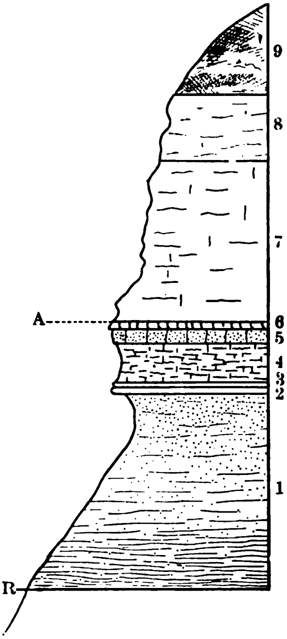


FIG. 311.—SECTION OF THE BLUFF AT BURLINGTON, IOWA. LOWER CARBONIFEROUS ROCKS. (C. A. White.) 1 to 6, "Yellow Sandstones"; 7 to 8, Carboniferous Limestone; 9, Drift; *R*, Mean Height of the River; *A*, Division between the two Groups.

in the Gray Mountains, California, near Ross' Ranch, 1,000 feet thick (? St. Louis), and at Pence's Ranch, eighty miles south, according to Whitney.

The distribution of the calcareous and fragmental materials of the Lower Carboniferous illustrates the principle heretofore explained, that, with increase of distance from the source of the sediments, the depositions become less fragmental, and more calcareous. The Carboniferous Limestones which, in southwestern Illinois, are 1,000 to 1,300 feet thick, become attenuated, eastward, to ten or twenty feet in southeastern central Ohio; while in the Appalachian region, 3,000 feet of soft reddish shales and sandstones (the Umbral Series) occupy the horizon of the Mississippi limestones. On the contrary, the Marshall, or fragmental group, which is 100 to 200 feet thick in Illinois, and 640 feet in Ohio, is represented in the Appalachians by 2,000 feet of coarse, grayish conglomerates and sandstones (the Vespertine Series), passing down into red sandstone, commonly regarded as of Catskill age. Locally, however, this lower group contains from eighty to eight hundred feet of limestone.

At many places in Pennsylvania and Virginia, the Vespertine Series contains beds of coal, one of which is two to two and a half feet thick, succeeded in Montgomery county, Virginia, at the distance of thirty to forty miles, by another bed six to nine feet thick, consisting of alternations of coal and slate. These deposits are sometimes called *False Coal Measures*. Lower Carboniferous coal beds occur also in Great Britain.

In Nova Scotia and New Brunswick, the Lower Carboniferous consists, also, of two epochs. The lower, or ***Horton Series***, is made up of red sandstones, conglomerates, and red and green marlites, intercalated with thin seams of coal. The Albertite (page 68) of the Albert mine is contained in a fissure in this series in New Brunswick. This fragmental group is chiefly developed northward in the vicinity of the Eozoic formations which supplied the sediments. The upper series, called the ***Windsor Series***, is developed chiefly southward, and as might be expected, consists mostly of limestones and marlites, but contains, also, extensive beds of gypsum.

3. *Geography of the Continent During the Lower Carboniferous Age.* The distribution of the sediments of the Lower Carboniferous shows that the Mississippi Valley was the site of a great interior ocean, which opened freely southward, but on the east was bounded by the great Seaboard Land which had first risen during or at the end of the Eozoic Æon, and which was bordered on the west by a belt of shallow sea, occupying the position in which the Appalachian chain was destined to be uplifted in a future age. This border was the theater of active fragmental deposition. The materials were derived from the wastage of the contiguous Seaboard Land, and perhaps a continental shore lying farther toward the northeast. The slow sinking of the sea bottom (perhaps accompanied by a sinking of the Seaboard Land) caused the accumulations to proceed to the extent revealed in the heavy beds of the Umbral and Vespertine

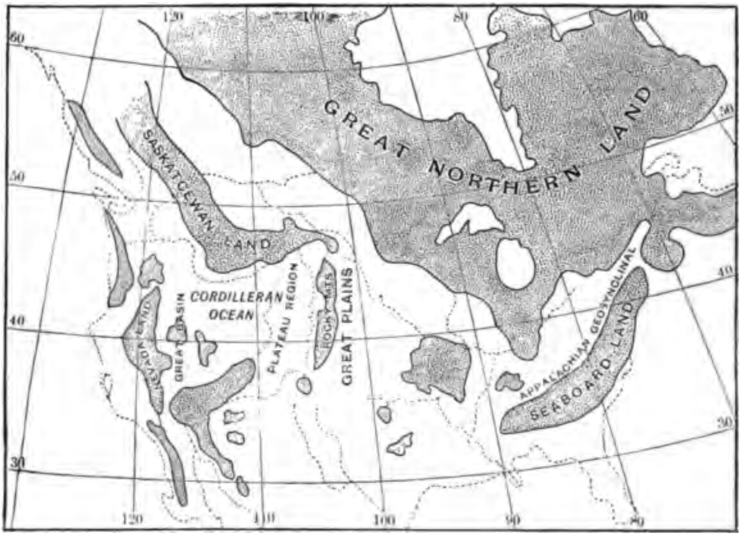


FIG. 312.—NORTH AMERICA, NEAR THE BEGINNING OF THE CARBONIFEROUS AGE.

series of eastern Pennsylvania. The remote interior was, meanwhile, the scene of crinoidal life and calcareous depositions. In the Mississippi valley, the fine arenaceous beds of the Marshall Group, resting on the Devonian, stretch toward northern Iowa. The northern limits of the overlying Burlington Limestone are 200 miles more southward, and the northern borders of the other divisions of the Carboniferous Limestone are fixed successively more to the south. This shows a gradual southward encroachment of the land. During the St. Louis epoch there was a temporary subsidence, but, as a rule, the higher members of the Group are southern in position, while the lower are northern.

In the midst of this interior ocean the great Cincinnati swell rose as a peninsula, stretching southward from the Michigan border, at which it bifurcated, sending one branch toward Ontario and New York, and the other toward Wisconsin — in each case to join the mainland. The greater part of the Michigan peninsula was an inland salt sea, like the modern Euxine, in which geological history proceeded somewhat independently, but yet under the same terrestrial conditions as determined the general tenor of physical and organic progress.

The Cordilleran region, which was a broad, mountainous belt at the end of the Eozoic, and then subsided to receive the sediments of the Cambrian and Silurian, continued to sink during Devonian and Carboniferous time. The source of the sediments was the Nevada land; and the greatest subsidence was westward. The whole Palæozoic series attains, according to King, a thickness of 1,000 feet in the eastern part of the Cordilleran region, 32,000 feet in the Wahsatch region, and 40,000 feet at the extreme western Palæozoic limit, longitude 117° 30′. At the close of the Palæozoic, the uppermost sheet of the Carboniferous, extending from the Nevada Palæozoic shore eastward to the Great Plains, was only interrupted by a few island-like granite peaks, which were above the level of deposition — the great mass of Eozoic topography having by that time been completely buried. Tongues and belts of these Carboniferous strata stretched west of the main Nevada shore, as indicated by the positions of gulfs and bays then penetrating even into the limits of the present states of California and Oregon.

4. *Erosion Features.* Like all limestones, the Carboniferous limestone has suffered greatly through the agencies of solution and erosion. The silicious or cherty nature of the Warsaw and St. Louis divisions has caused very unequal weathering, and hence a very rugged aspect in the landscape of the so called "Knobs." The St. Louis division is especially abundant in caverns in Indiana, Kentucky, and Tennessee. These may be regarded as dating back to the beginning of the Mesozoic Æon. Whatever fissures may have been produced by movements of the earth's crust, have been continually enlarged in later times by percolating waters. The Mammoth Cave, a plan of which has been given in Fig. 209, is probably the greatest result known of cave-making agencies.

Many of these caves have contained extensive deposits of various salts, especially of a lime saltpetre, or nitrocalcite. The great limestone formation in the Cumberland Table Land contains hundreds of "nitre caves," which, in the early part of the present century, especially in 1812–1814, were industriously worked for nitrocalcite for the manufacture of nitre.

5. *Organic Remains.* The organic remains of the Lower Carboniferous indicate a fauna that differed in important particulars from that of the Devonian. The type of corals was less luxuriant, both in respect to the tribes of Cup Corals (Tetracoralla) and those of Tabulate Corals (Hexacoralla), but especially the latter. The compound cup coral, *Lithostrotion*, however, is a common and characteristic species of the widely spread St. Louis Limestone; and simple cup corals, indeed, remained in conspicuous abundance. But the crinoidal type expanded to a splendid culmination (see description, page 324). The limestone of the upper part of the bluff at Burlington, Iowa (Fig. 311), is in some of its beds composed chiefly of the broken stems and the calices of crinoids. This locality is classical ground for the palæontologist. Mr. Charles Wachsmuth has collected here 355 species belonging to 44 genera. Crawfordsville, Ind., is another

productive locality. The state of preservation of the crinoids is even better than at Burlington, the rock being an argillaceous shale; but the number of species does not exceed 100, according to Professor D. A. Bassett, who states that several thousand specimens have been removed. The principal genera are *Actinoc'rinus*, *Baryc'rinus*, *Cyathoc'rinus*, *Dichoc'rinus*, *Forbesioc'rinus*, *Goniasteroidoc'rinus*, *Onychoc'rinus*, *Platyc'rinus*, *Scaphoc'rinus*, and *Taxoc'rinus* (Bassett). The beds here are of Keokuk Limestone. The higher divisions, also, from southern Illinois to northern Alabama and the Cumberland Table Land, are generally well stocked with the remains of crinoidal life. Fig. 234 gives a view of a crinoid from the Waverly group of Ohio — the epoch of the great expansion of the type under its specially Carboniferous aspect.

Straight chambered shells were still in process of disappearance; but the coiled *Goniatites* and *Nautili* were very abundant (see page 326); and Lamellibranchs were increasing in numbers and diversification — especially in the earlier periods. Brachiopods were on the decline. The old genera, *Strophomena*, *Leptæna*, *Orthis*, and others, were near extinction. *Spirifera* was represented in numerous species, many of large size, and *Syringoth'yris* made its advent into America and Europe. *Producta* and *Chonetes* were characteristically abundant. The last of the Trilobites now lived, greatly dwarfed in bulk; but higher Crustaceans were taking their place. Fishes were in the high career of advancement; but none belonged yet to the modern type of Teleosts. They were either Ganoids or Selachians; and of the latter, the Cestraciont type was peculiarly prominent. The forms of life here mentioned should be again studied on pages 331–335.

§ 7. The Upper Carboniferous System.

1. *Divisions, Subdivisions, and Terms.*

  II. **Permian Group.**

  I. **Coal Measures.**

    2. UPPER COAL MEASURES.

    1. LOWER COAL MEASURES. "Lower Coal Measures" of Rogers.
      Conglomerate Measures.

The term Permian is derived from the province of Perm, in Russia, in which a group of strata of this age was described as a "System." It consists, in Europe, of two principal divisions, and hence is often called the "Dyas."

The details of the stratification of the Coal Measures are not identical at remote points; but a general correspondence exists through western Pennsylvania and Ohio, from which a standard series of formations has been drawn up, as shown below. For the parallelisms of the Ohio coals I depend on Orton's recent and important Report. In Indiana, western Kentucky, and Illinois only a more general correspondence has been traced. In regions still more remote the correspondence is reduced to the existence of a series of shales, sandstones, coal beds, occasional limestones, and one or more considerable conglomerates at or toward the bottom of the series.

Standard Section of the Coal Measures, Specially Suited to Western Pennsylvania and Eastern Ohio.

UPPER COAL MEASURES. THICKNESS, 1,700 FEET.

V. **Upper Barren Measures** of Rogers, 974 ft., containing 6 coal beds, 8 ft., and having at bottom,—
  46. Waynesburg Sandstone.

IV. **Upper Coal Measures** of Rogers = Monongahela Series.
  45. **Waynesburg Coal,** 6 ft. (I), XXI.
  44. Pittsburgh Sandstone, Shales, and *Limestones.*
  43. **Pittsburgh Coal,** 8 ft. (H), Cumberland, Md., Pomeroy Bed, Ohio, Primrose bed of Anthracite. XX.

III. **Lower Barren Measures** of Rogers = Pittsburgh Series.
  42. Upper Pittsburgh *Limestone,* 2 ft.
  41. Lower Pittsburgh *Limestone,* 5 ft.
  40. Morgantown Sandstone, 45 feet = 1st "Oil Sand," Dunkard's Creek.
  39. **Elk Lick Coal,** 3 ft. (F?) (G?), XIX.
  38. Elk Lick *Limestone,* 2 ft.,
  37. **Berlin Coal,** 3 ft. (F?). XVIII.
  36. Green Crinoidal or Berlin *Limestone,* 2 ft.
  35. **Platt? Coal,** 1½ ft., XVII.
  34. **Price Coal,** XVI.

33. **Bakerstown Coal,** 2½ to 4 ft., XV.
32. Pine Creek *Limestone*, 2 ft.
31. Buffalo Sandstone = Upper Mahoning S.
30. Brush Creek *Limestone.*
29. **Brush Creek Coal,** XIV.
28. Mahoning Sandstone, 40 to 80 ft., and Shale 50 ft. Lower Mahoning. ? Anvil Rock S.; Kurlew S., Ky. = 2d "Oil Sand," Dunkard's Creek — the principal reservoir. A "gas rock."

LOWER COAL MEASURES. THICKNESS, 642 FEET.

Don't dup

II. Lower Coal Measures of Rogers. Thickness, 392 ft. = Allegheny Series.

FREEPORT GROUP.

27. **Upper Freeport Coal,** 4 ft. (E), Muskingum County and Valley. "Mammoth Bed" of Anthracite, XIII.
26. Upper Freeport *Limestone*, 3 ft. White L., Ohio.
25. Upper Freeport Sandstone, 30 ft. Butler S.
24. **Lower Freeport Coal,** 2 ft. (D). Unreliable in Pennsylvania, XII.
23. Lower Freeport *Limestone*, 2½ ft. Butler L.
22. Lower Freeport Sandstone and Shale, 75 ft. Freeport S.

KITTANNING GROUP.

21. **Upper Kittanning Coal,** 1½ to 3 ft. (C′). Blacksmith Vein, XI.
20. **Middle Kittanning Coal,** 3 to 6 feet. Little known in Pennsylvania. Coshocton, Ohio; Great Vein of Hocking Valley, Ohio, X.
19. **Lower Kittanning Coal,** 2½ ft. (C). "Kittanning" of Rogers, IX.
18. Kittanning Clay, 10 ft. New Brighton Fire Clay.
17. Kittanning Sandstone, 42 ft. Lower Kittanning S.; Industry S, Ohio.

CLARION GROUP.

16. Ferriferous *Limestone* and Buhrstone Ore, 1 to 15 and 20 ft.
15. **Upper Clarion Coal,** 2 ft. Scrubgrass; Canfield Cannel, VIII.
14. **Lower Clarion Coal,** 1½ ft. (B). Clarion Coal, VII.
13. Putnam Hill *Limestone.* Not in Pennsylvania.
12. **Brookville Coal,** 2 ft. (A). Mahoning Valley Coal. VI.

I. Conglomerate Measures. Thickness in Ohio, 250 ft. = Seral Conglomerate of Rogers (No. XI) = Sharon Coal Series of Hodge = Pottsville Conglomerate.

BEAVER RIVER GROUP.

11. Homewood Sandstone, 75 to 155 ft. Seral Conglomerate. Tops of Pottsville Conglomerate; Piedmont Sandstone; Tionesta Sandstone; Upper Homewood Sandstone.
10. **Tionesta Coal,** 3 ft., V.
9. Upper Mercer *Limestone* and Ore, 2½ ft. Mahoning Limestone.
8. **Upper Mercer Coal,** 2 to 5 ft., IV.
7. Lower Mercer *Limestone* and Ore, 2½ ft. Mercer Limestone; Zoar L.
6. **Lower Mercer Coal,** 2½ to 3 ft. Lower Porter of Rogers, III.
5. Conoquenessing Sandstone (Upper), 45 ft. Lower Pottsville Conglomerate; Lower Homewood Sandstone; Massilon Sandstone (part) in Ohio = 1st "Mountain Sand."
4. **Quakertown Coal,** 3 ft. (and Shales), II.
3. Conoquenessing Sandstone (Lower), 25 ft. Massilon Sandstone (part).
2. **Sharon Coal** (and Shales), 4 to 6 ft. Block Coal of Mahoning Valley; Brier Hill Coal; Massilon Coal, I.
1. Sharon Conglomerate, 30 feet. In Pennsylvania, Garland Conglomerate and Olean Conglomerate. In Ohio, Ohio Conglomerate part or all = 2d "Mountain Sand."

This series is followed downward, in Pennsylvania, by the "Shenango Sandstone" or "Ferriferous Fish Bed," (=Sub-Garland = Sub-Olean) and the Meadville Upper and Lower Limestones, belonging to the Lower Carboniferous.

Most of the standard terms in the foregoing table are from Pennsylvania Geology. The capital letters in parentheses, following the names of coal seams, were applied by Lesley to the Pennsylvania series above the Seral Conglomerate. Serial numbers for the entire Coal Measures, based on the latest determinations of the Pennsylvania and Ohio Surveys, here follow the names of the coal beds in Roman capitals.

It has generally been considered that the Coal Measures proper consisted of the formations above what is here designated Conglomerate Measures; and that the "Conglomerate" or "Millstone Grit" of the English formed a natural boundary. But it is found that the supposed basal Conglomerate lacks the uniformity and persistence and constancy of stratigraphical position once assumed; and that the system of coal beds, even including limestones, continues below the conglomerate horizon, giving, along the Appalachian belt, some of the thickest and best deposits—sometimes known as "False Coal Measures." It is found, also, that the only coal of Arkansas is subconglomerate. In Tennessee the Sewanee coal bed is 230 feet below the Conglomerate, and 371 feet above the Carboniferous Limestone. For such reasons geologists (Lesley, J. J. Stevenson, Orton) incline to treat as one group the entire series of strata, both above and below the "Conglomerate."

The "Conglomerate," being an ambiguous term, was replaced, in 1860, by the present writer, with the geographical designation "Parma Conglomerate." Subsequently, for similar reasons, it received, in Canada, the name Buenaventure Conglomerate.

The student will understand that the Table does not enumerate the complete sequence of strata, but only the salient formations, which possess economic or stratigraphical importance, and serve as landmarks in the grand succession of deposits.

2. *Distribution.* The coal-producing Coal Measures are confined, in America, to the region east of the Rocky Mountains. The locations of the various coal fields will be learned from the Geological Map: (1) The *Appalachian Coal Field*, having a length of 875 miles, and a breadth ranging from 30 to 180 miles, with an area of 59,000 square miles. (2) The *Eastern Interior*, or that of Illinois, Indiana, and northwestern Kentucky, 47,000 square miles. (3) The *Western Interior*, or that of Iowa, Missouri, Kansas, Arkansas, and Indian Territory, 18,000 square miles. (4) The *Michigan*, 6,700 square miles. (5) The *Rhode Island*, 500 square miles. (6) The *Acadian*, or that of Nova Scotia and New Brunswick, 18,000 square miles.

In the Rocky Mountains and beyond, Coal Measure limestones are known to occur in Montana, Wyoming, Colorado, Utah, Nevada, and California; but all the coal west of Omaha to the Pacific coast is Mesozoic or Cænozoic.

The accompanying Coal map of Pennsylvania and Ohio shows the interrupted attenuations of the six Pennsylvania bituminous basins, and indicates the distribution of the anthracite coal of eastern Pennsylvania. Their names are as follows: (1) Southern or Schuylkill Basin and Mine Hill, 146 square miles; (2) Shamokin (50), Mahonoy (41), and Lehigh (37) Basins, 128 square miles; (3) Wyoming and Lackawana Basin, 198 square miles. Total anthracite area, 472 square miles. The conglomerates of the lower portion of the Coal Measures generally extend, as in northeastern Ohio, considerably beyond the areas covered by the coal beds. They often lie in huge cuboidal blocks dislocated from the formation, as in the southern counties of New York, where they form "Rock Cities" and "Ruined Cities." The same may be seen along the western border of the eastern coal field of Kentucky, and along the brow of the Cumberland Table Land, where masses as large as dwelling houses have been broken off and rolled down the steep escarpment.

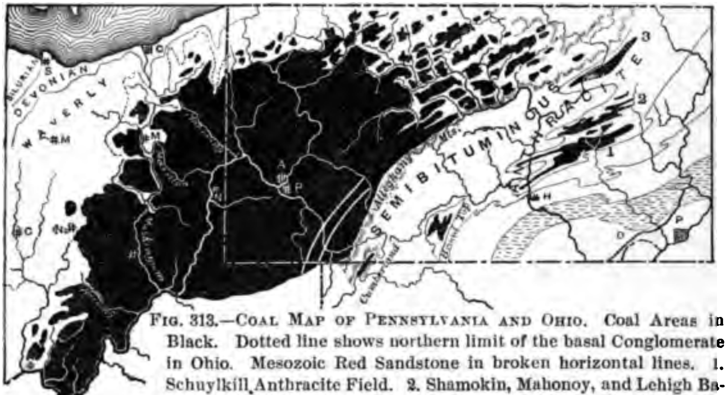


FIG. 313.—COAL MAP OF PENNSYLVANIA AND OHIO. Coal Areas in Black. Dotted line shows northern limit of the basal Conglomerate in Ohio. Mesozoic Red Sandstone in broken horizontal lines. 1. Schuylkill Anthracite Field. 2. Shamokin, Mahonoy, and Lehigh Basins. 3. Lackawana and Wyoming Basin. *D*, Great Dike. *F*, Fault.

NOTE.—Several great faults run parallel with the Appalachian folds. One remarkable fault extends along the Great Valley of Virginia by the ridge called North Mountain (see Fig. 92), and into Pennsylvania. Another one, of 20,000 feet, occurs near Chambersburg, bringing Cambrian strata up to a level with upper Devonian.

3. *Kinds of Rocks.* The Conglomerate series presents generally a conspicuous conglomeritic mass, which has in southern New York a thickness of 25 to 60 feet. In the anthracite region it is 1,000 to 1,500 feet thick, thinning westward to 250 feet on

the Ohio River, including all the associated strata. The nature of this change in thickness indicates the eastern origin of the detrital materials in the great Seaboard Land, as we believe.

The Coal Measure strata, including the Conglomerate series as well, embrace shales, clays, limestones, sandstones, and beds of iron ore and coal. Something of their arrangement may be learned from the Table on page 403. It must be understood, however, that this is not a full enumeration of the strata. Rogers enumerated, for instance, one hundred important strata and formations above the Homewood Sandstone, and left 200 feet at the top of the Measures unspecified. Every bed of coal, as a rule, is understood to be underlaid by fire clay. It is often accompanied by shales and sandstones. Thus, the Upper Freeport Coal has underneath, 50 feet of sandy shales. The Lower Freeport Coal has above, 4 feet of bituminous shale, and below, 2 feet of fire clay. The Lower Kittanning Coal is followed downward by the Kittanning clay, 8 feet; sandy shales or sandstone, 25 feet; buhrstone iron ore, 1 foot; Ferriferous Limestone, 15 feet; Scrubgrass coal, 2 feet; shales, etc., 25 feet; Clarion Lower Coal, 3 feet.

The fundamental order of stratification given in the Table has been traced from western Pennsylvania into Ohio; but the shales and sandstones are subject to great variation. The coal beds and the limestones are the most persistent features, and these are the means of parallelizing the measures at remote localities. The Lower Mercer Limestone, for instance, has been widely used as a geological guide. It is thin, but wonderfully persistent. Its color is dark blue, or almost black, with thickness from one to three feet; contains much iron and silica and an abundance of fossils, and is everywhere overlaid by excellent iron ore. The Upper Mercer Limestone is very similar, but less uniform, and is also accompanied by iron ore and a seam of coal. The Ferriferous Limestone is the centre of a group of strata, comprising, besides the limestone, the best iron ore, the largest clay deposits, and several of the most widely worked coal seams of the Lower Coal Measures. This group of formations serves to identify the horizon. The limestone is 15 to 20 feet thick, pure light gray above and grayish-blue below, frequently with a deposit of buhrstone at top, and with this a valuable bed of iron ore. The limestone, also, is full of fossils. This recurrence of similar deposits in relation to successive limestones will be understood as an aspect of the cycle of sedimentation (page 268).

The so called "Mammoth Bed" B has been identified at the following points: Leonard's, above Kittanning, Pa. (3½ feet); Mahoning Valley, Cuyahoga Falls, Chippewa, etc., Ohio; the Kanawha Salines; the Breckenridge Cannel Coal and other mines in Kentucky, the first (or second) Kentucky Bed; the lower coal on the Wabash, Ind.; Morris, etc., Ill.; Murphysborough, Ill.; Clinton, Mo. [250 species of plants].

The Pittsburgh Bed, H, at the following points: Cumberland, Md.; Wheeling; Athens, Ohio; the Pomeroy Bed, Ohio; Mulford's in western Kentucky, the 11th Kentucky Bed. This bed underlies an area of 14,000 square miles.

The lowest coal beds are most developed in the Appalachian region. In the Schuylkill Basin we have 15 coal seams, each from 3 to 25 feet thick, in all 113 feet of coal, of which 80 feet are marketable. In the second and third basins there are 60 feet of coal. The Upper Coal Measures are more developed in western Pennsylvania, and relatively still more in the states farther west. The coal beds which are anthracite in eastern Pennsylvania are semi-bituminous in middle Pennsylvania, bituminous at Pittsburgh, and more bituminous in Ohio and Indiana. As we go westward, the Coal Measure limestones grow thicker, and, of the coal beds, the lower coals disappear, and the upper diminish in thickness and value.

The characteristics of the different varieties of coal have been given in Part I, Study XIII.

The Coal Measure rocks in the Wahsatch Range consist of Upper Coal Measure limestones, 2,500 to 3,000 feet; Middle Coal Measure quartzites, 5,000 to 7,000 feet; Lower Coal Measure limestones (Wahsatch Limestone) amounting, with Lower Carboniferous and Upper Devonian limestones, to 7,000 feet.

In the Eureka district of Nevada, the Lower Coal Measures consist chiefly of heavy-bedded dark blue and gray limestone, 3,800 feet; followed upward by the "Weber Conglomerate," 2,000 feet. The Upper Coal Measures are light-colored blue and dark limestones, 500 feet.

4. *Geological Structure*. Beds of coal, being mere stratified rocks, have been subjected to all the tilting, folding, and metamorphism which have affected contiguous strata. In most parts of the Mississippi Valley, the disturbances of the strata amount seldom to more than gentle undulations. The coal beds, therefore, are often quite continuous and uniform. The gentle undulations, however, frequently bring them within reach of surface erosions, and thus the continuity of a coal bed, or of several beds, is frequently interrupted, as shown in Fig. 314, which represents the general position of the coal strata in the West. In Ohio the Coal Measures have undergone very little disturbance, as may be inferred from the section in Fig. 315, taken in the northeastern part of the state.

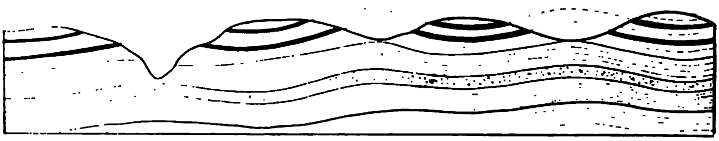


FIG. 314 SECTION IN A REGION OF UNDULATING COAL MEASURES.

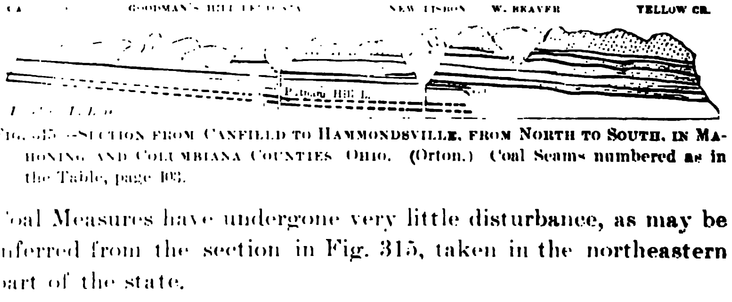


FIG. 315.—SECTION FROM CANFIELD TO HAMMONDSVILLE, FROM NORTH TO SOUTH, IN MAHONING AND COLUMBIANA COUNTIES, OHIO. (Orton.) Coal Seams numbered as in the Table, page 103.

In Illinois, the Coal Measures have suffered moderate disturbances. The "Shawnee Fault" crosses the coal field from east to west near its southern extremity; and another fault crosses the whole length of the coal field nearly north and south. The former crosses the Mississippi River at Bailey's Landing, in

Missouri. In Jackson county, Illinois, it brings Devonian limestone to the surface at the Bake Oven and Bald Bluff, on the Big Muddy, where it stands on an inclination of 25°. It continues across the state, and crosses the Ohio River near Shawneetown, into Kentucky, whence it continues eastward to Bald Hill, in Union county, and as far as the eastern boundary of Henderson county. The other Illinois axis of disturbance enters the state in Stephenson county, on the north, intersects Rock River at Grand Detour, and the Illinois River at Split Rock, between La Salle and Utica, and continues S. 20° E. to the Wabash River, in Wabash county. It brings the St. Peters Sandstone to the surface on Rock River, and the Lower Magnesian on the Illinois. These, and other smaller disturbances which have taken place since the Coal Period, combine with erosions in breaking up the continuity of the Coal Measures in Illinois.

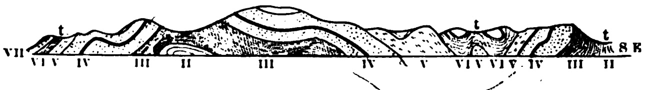


FIG. 316.—SECTION FROM THE GREAT NORTH TO THE LITTLE NORTH MOUNTAIN, THROUGH BORE SPRINGS, VA. (Rogers.) *t*, *t*, *t*, Thermal Springs; *II*, Calciferous; *III*, Trenton; *IV*, Cincinnati; *V*, Oneida: *VI*, Clinton and Lower Helderberg; *VII*, Oriskany and Cauda-galli.

A still more disturbed condition of the Coal Measures is illustrated in Figs. 33 and 34. The great folds of the Appalachians involve the various beds of coal in a complexity of structure whose unfolding has taxed the highest skill of geologists. Fig. 316 is an example of the shape into which foldings and erosions have brought strata originally horizontal and continuous. Fig. 92 is another illustration of Appalachian disturbance. The anthracite coal basins present a series of valuable coal beds in an extraordinary state of distortion, which brings within a given surface area an amount of coal which would not be suspected from the area and the thickness of the beds. In Fig. 317 we have a section across the east end of the First, or Schuylkill Anthracite Basin, not far from Mauch Chunk, Pa. It represents a depth of about 2,000 feet, and shows two of the grand folds of the Appalachians (1 and 2), and three intermediate smaller ones (3, 4, 5).

It has been said, in speaking of the Lower Carboniferous System, that each successive division in the Mississippi Valley has its northern limit, as a rule, a little farther south. This is evidence of progressive upheaval northward, while the sedimentation was going on. On the contrary, the succession of beds in the Upper Carboniferous indicates progressive subsidence northward while the Coal Measures were in formation. Each successive stratum finds its northern limit a little farther north, so that not only is the Carboniferous Limestone covered by the Coal Measures in northern Illinois, but also the Devonian and Silurian; and the northern extremity of the coal field even laps over on the Cambrian of northern Illinois. All this is shown on the Geological Map. If, then, a section were to be constructed through the western part of the Illinois coal field, the northern portion of it would present the general appearance of Fig. 318. Here the older strata, *E*, *C*, *S*, were slowly rising, while the Lower Carboniferous sediments were accumulating; they were sinking while the Coal Measures, *M*, were forming; and at a subsequent epoch they have been reëlevated to their present position.

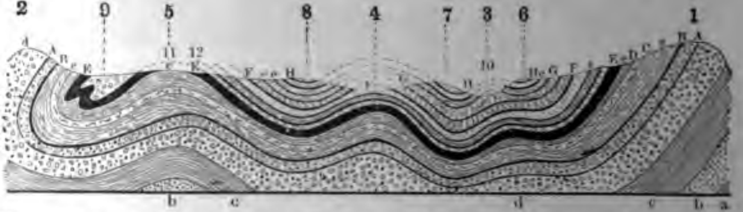


FIG. 317.—SECTION NEARLY NORTH AND SOUTH ACROSS NESQUEHONING COAL BASIN, NEAR MAUCH CHUNK, PENNSYLVANIA. (Macfarlane.) 1, Locust Mountain; 2, Sharp Mountain; 3, Anticlinal, No. 2 (Rothwell); 4, Anticlinal, No. 3; 5, Anticlinal, No. 4; 6, Synclinal B (Rothwell), 7, Synclinal C; 8, Synclinal D; 9, Synclinal E; 10, Panther Creek; 11, Summit Hill; 12, Old Coal Quarry.

COAL SEAMS.—*A* (Rogers), 4 ft.; *B* (Rogers), 5 ft.; *C*, *D*, Small Seams; *E* (Rogers), Mammoth Bed, 25 ft.; *F*, Red Ash, or Pencil Seam, 15 ft.; *G* (Rothwell), Brown Bed, 5 ft.; *H*, Small Upper Red Ash Seams. *a*, Red Shale (Catskill); *b*, Vespertine Sandstone; *c*, Umbral Shale; *d*, Seral Conglomerate; *e*, Slates and Sandstones between Coal Beds.

√ 5. *Coal Mining.* Had the coal beds been left in the positions in which they were formed, our great repositories of mineral fuel would have been practically hidden from observation. To the tiltings and foldings of the rocks we are indebted for the disclosure of the buried stores, and for the cheapest method of extracting them. Beds of coal often outcrop on hillsides and in ravines (Figs. 314 and 317), and may be followed into the earth. Their place of outcrop, however, is generally indicated only by a dark band along the surface, or by coal fragments scattered in the vicinity — generally southward. When, by excavating, the bed is struck, it is found altered, by weathering, to a depth of thirty to fifty feet. Such coal is pulverulent, or soft, browned, and friable, and not marketable. Fig. 319 shows the method of *drifting* in on a hillside. If possible, the spot is so chosen that the mine water will flow out at the entrance. If otherwise, pumps must be employed. When a region is known to be underlaid by coal, a *shaft* may be sunk, though no coal appears at the surface. This is illustrated in Fig. 320, which represents the Upper Measures of western Pennsylvania (see the Table, page 403); though, in fact, the surface of the country is such that

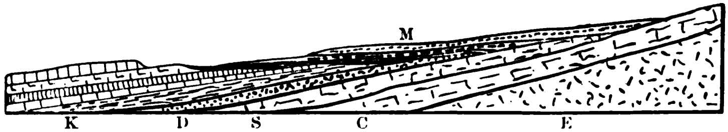


FIG. 318. - IDEAL SECTION IN ILLINOIS, SHOWING UNCONFORMITY BETWEEN THE COAL MEASURES AND OLDER ROCKS. *E*, Eozoic; *C*, Cambrian: *S*, Silurian; *D*, Devonian; *K*, Kinderhook, followed by Lower Carboniferous Limestones; *M*, Coal Measures.

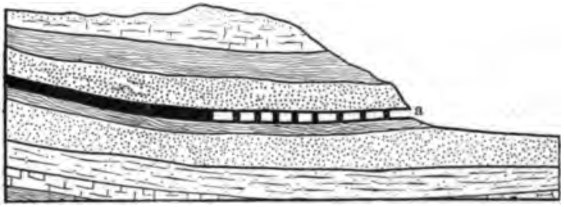


FIG. 319.—DRIFTING IN ON A COAL BED. *a*, Mouth of the Drift.

most mines in that region are approached by drifts, or are worked by *slopes*. The *shaft*, *S*, is the means of access to the coal beds, *W* and *P*. The *sump*, *u*, is sunken to receive the water, which is thence pumped out by machinery. When a coal bed, *W*, is reached, excavations are made on both sides. Often the same shaft is sunk to a second coal bed, *P*, and occasionally even to a third one. The passages, or *gangways*, are generally extended in straight lines to the limits of the property, or as far as the coal continues satisfactory; and other passages are opened at right angles with these. There are different systems of planning the underground work of a mine, but that most employed is illustrated in Fig. 321, which shows the plan of the mines worked by a powerful and well known company in the Blossburg coal region, of Pennsylvania — a region embracing, also, the celebrated Morris Run and Fall Brook Mines.

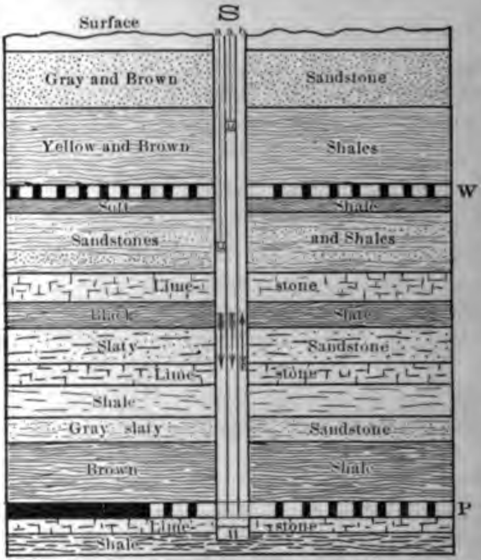


FIG. 320 — CONDENSED SECTION IN THE UPPER COAL MEASURES OF PENNSYLVANIA, SHOWING METHOD OF MINING THROUGH A SHAFT. *W*, Waynesburg Seam; *P*, Pittsburgh Seam; *S*, a Mining Shaft; *a*, *a*, Down Cast; *b*, Up Cast; *u*, Sump.

The plan of working presented shows the condition of the Arnot mines in 1872. Here is a portion of a coal bed about 1,500 feet broad and 1,900 feet long, showing where the gangways have been dug out for travel and for ventilation, and also the " rooms " or " breasts ' from which the coal has been taken. It shows also the large amount of coal left for supporting the roof. These supports will ultimately be taken out also. In some regions the roof rock is so fragile that the gangways have to be timbered. Even then the enormous weight sometimes crushes the supports, and disasters happen. The same plan of mining is pursued whether the mine is approached by an adit, as shown in Fig. 319, or by a shaft, as in Fig. 320.

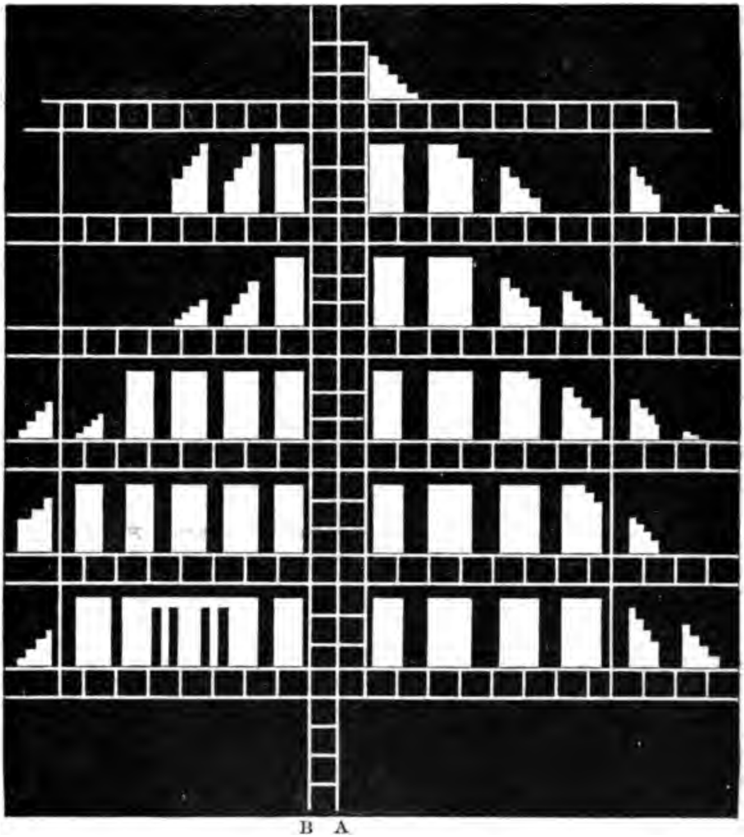


FIG. 321.—PLAN OF THE MINES OF THE BLOSSBURG COAL CO., AT ARNOT, PA. SCALE 400 FT. TO THE INCH. (After Macfarlane.) *A*, the Main Gangway; *B*, the Return Air Course and Ventilating Shaft. The light portions represent the ground worked over to 1872.

In the anthracite, and occasionally in bituminous, coal regions mining is done by *slopes*, which are simply inclined planes or sloping tunnels underground, generally cut in the coal seam to avoid "dead rock." Drifts, which are always most economical, are generally practicable in the bituminous coal regions of Pennsylvania, Ohio, eastern Kentucky, Tennessee, Georgia, and Alabama; but in the less disturbed and less denuded regions of Illinois and Michigan resort must generally be had to shafts.

6. *Organic Remains.* The coal itself affords abundant traces of vegetation, but generally they are obscure and unidentifiable. Spores and spore cases of *Lycopodium*-like plants (Lepidodendrids) are, however, extremely abundant — the spores appearing as minute grains. Vegetable structure may also be detected, even in anthracite, by preparing thin sections and rendering them as translucent as possible. The associated shales are often richly stocked with fronds of ferns and fragments of flowerless plants. They are closely pressed on the surfaces of the laminæ, and preserve all the delicate structures of the plant in such perfection as fully to reveal its nature. Remains of plants are also often disseminated through the sandstones; and here occur, sometimes, considerable fragments of tree trunks. In some remarkable instances such trunks have been found still in an erect position,

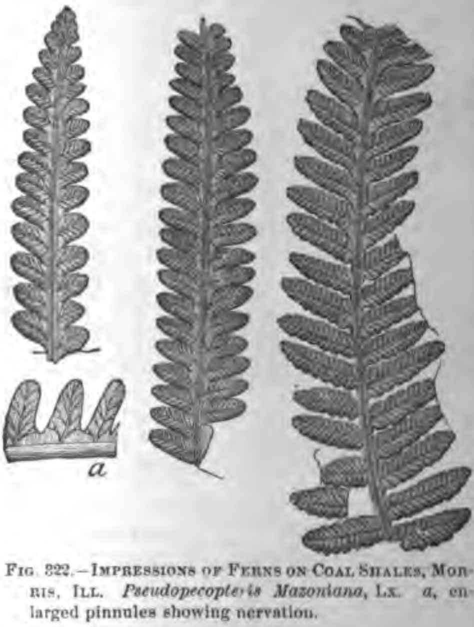


FIG. 322.—IMPRESSIONS OF FERNS ON COAL SHALES, MORRIS, ILL. *Pseudopecopteris Mazoniana*, LX. *a*, enlarged pinnules showing nervation.

together with other growths in their original situations, as at the Joggins, in Nova Scotia, Fig. 323. The limestones embraced in the Coal Measures contain, of course, the relics of marine forms — especially Brachiopods, Bryozoa, Crinoids, and Fishes. These limestones and their included faunæ become largely developed in Illinois, as at La Salle, and increase westward.

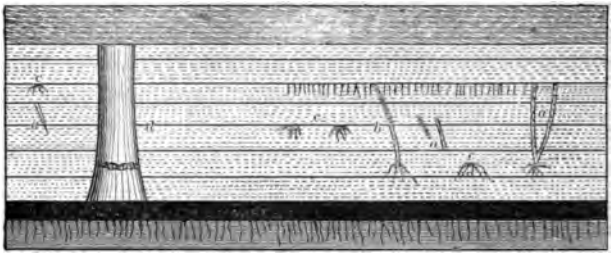


FIG. 323.—ERECT STUMPS IN SANDSTONE OF THE COAL MEASURES AT THE JOGGINS, NOVA SCOTIA, WITH ROOTLETS IN THE UNDERCLAYS. (Dawson.)

A synopsis of the classification of plants is given on page

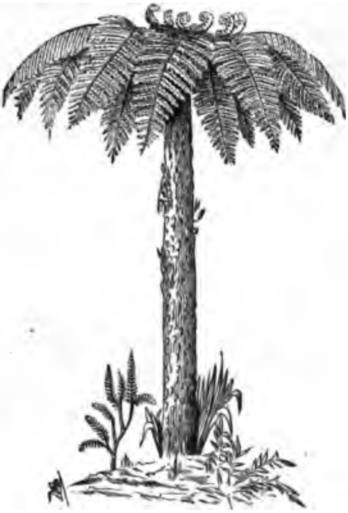


FIG. 324. — LIVING TREE FERN. (After Brogniart.)

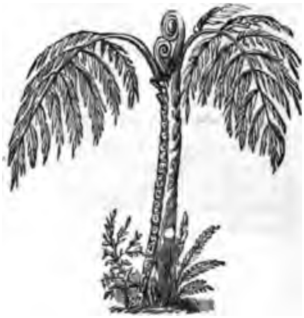
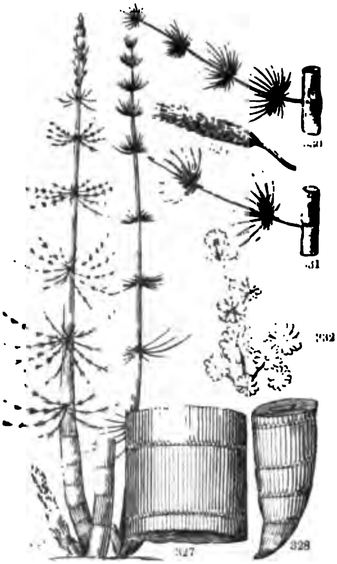


FIG. 325.—*Megaphytum*. A COAL FERN RESTORED. (After Dawson.)

305. The terrestrial types most abundant in the Coal Measures were already well represented in the later Devonian. They were

mostly *Acrogens* or ***Pteridophytes*** of the classes Ferns, Calamarians and Lycopods; though some Gymnosperms were also present, especially *Cordaites*, and possibly also a few Angiosperms. No remains of Mosses were known until the very recent discovery of several species at Commentry, in France. The stems are found three to four centimetres long. Only a single Fungus is known in America, and that from Cannelton, Pa. (Lesquereux). No American Palms or other Angiosperms are known. The Ferns were partly Tree Ferns, and the whole group is now nearly extinct. A few species survive on the slopes of high mountains near the equator or on tropical islands in the Pacific Ocean. A living Tree Fern is shown in Fig. 324, and a fossil species, restored by Dawson, is reproduced in Fig. 325. The "scars" left on removal of the leaves of a Tree Fern are quite characteristic, and are a principal means of distinction among the fossil species.

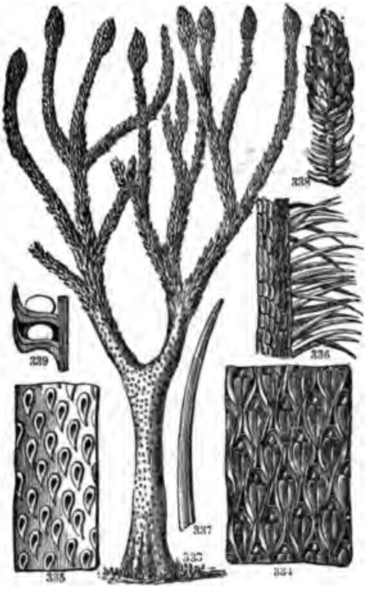


FIGS. [illegible] CALAMARIANS. 326. Cal- [illegible] Dawson, with [illegible] 327. Sec- [illegible] 328. The root. 329 [illegible] *Asterophyllites* [illegible] the [illegible] two gen- [illegible] representing [illegible] of Calamites.

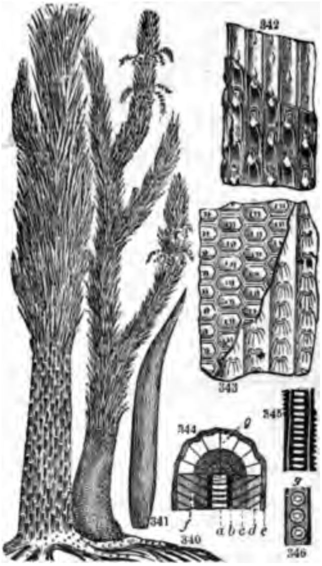
The greater part of the Coal Measure ferns were herbaceous. The commonest species belong to the *Neuropteris*, ***Pseudopecopteris*** (Fig. 322), ***Sphenopteris***, and *Pecopteris* families.

The Calamarians were related to the modern ***Equiseta*** or Horsetails. Modern *Equiseta* are small, herbaceous plants, but the extinct *Calamites* attained a height of thirty feet. The principal genera are *Calamites* (Figs. 326–329), ***Asterophyllites*** (Figs. 330, 331), *Annularia* (Fig. 332), and ***Sphenophyllum.***

Asterophyllites and *Annularia*, generally treated as distinct from *Calamites*, are by some regarded as merely stems and leaves of that genus. More recently they are thought to be related to Lycopods.



FIGS. 333-339.—*Lepidodendron*. 333, *Lepidodendron* restored (after Dawson). 334, 335, Pieces of Bark, showing the "scars." 336, Branch with leaves. 337, Leaf. 338, Fruit cone. 339, Two scales of the Fruit cone with Fruit (enlarged).



FIGS. 340-346.—*Sigillaria*. 340, *Sigillaria* restored (after Dawson). 341, A Leaf. 342, 343, Pieces of Stem of two different species, with Bark adhering, showing Scars of bark and wood. 344, Ideal section of Stem, showing (*a*) Pith, (*b*) Vascular cylinder, (*c*) Inner layer of Wood, (*d*) Outer layer of Wood, (*e*) Bark, (*f*) Vascular threads going from the vascular layer to the leaves, and (*g*) Medullary Rays. 345, A Scalariform vessel from the inner layer of wood. 346, Perforated vessel from the outer layer of wood.

The class of Lycopods includes among extinct forms, *Lepidodendron* and *Sigillaria*. In coal production they hold a place of first importance. *Lepidodendron* was a genus of large trees related to our humble ground pines and *Selaginella*. The bark was marked by scars arranged in quincunx order as shown in

Figs. 334 and 335. In the accompanying illustrations we have a restoration of *Lepidodendron*, after Dawson, with separate parts on a larger scale.

Sigillaria was a closely related genus of large trees. It is at once distinguished from *Lepidodendron* by having its trunk scars arranged in vertical series instead of diagonal. The parts of *Sigillaria* are illustrated in Figs. 340–346.

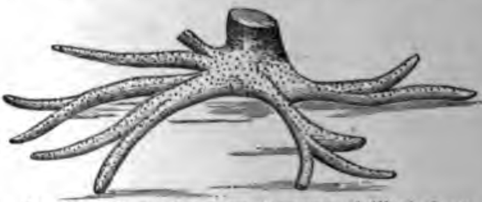


FIG. 347.—*Stigmaria* AT THE BASE OF A *Sigillaria* STEM.

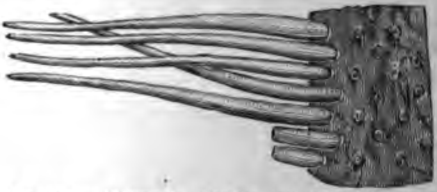


FIG. 348.—*Stigmaria ficoides* (SO CALLED), WITH ROOTLETS ATTACHED.

Stigmaria (Figs. 347, 348) is merely the subterranean part of a *Sigillaria*.

The types of plants thus noticed have evidently formed the principal part of the coal.

Lepidodendron and *Sigillaria* sustain relations to modern *Lycopodium* and *Selaginella*, but differ in the presence of pith; to *Cycadeæ*, in the fibro-vascular cylinder (Fig. 344, *b*); to Firs, in their disc-bearing, minute vessels (Fig. 346); and to Ferns, in their scalariform vessels (Fig. 345) and scarred stem left by fallen fronds (Figs. 334, 335, 342, and 343). They are, therefore, striking illustrations of comprehensive types. They represent an early stock existing while yet there were neither characteristic Gynosperms, Cycads, nor Angiosperms; but out of which all these types were to be gradually unfolded.

The marine life of the Upper Carboniferous comprises mostly the family types descended from the Devonian. Even most of the genera are the same.

Air-breathing animals now formed a conspicuous part of the fauna. Land Snails, Myriapods, and Neuropterous Insects, with some Orthopters, became comparatively abundant. Crustaceans increased, but the type of Trilobites now made its last appearance. Ganoid and Selachian Fishes continued abundant. The remains of Amphibians proclaim, like the other air breathers, the increasing importance of the land. But they were mostly scaled and plated Amphibians, combining ganoid, amphibian, and reptilian characters.

7. *Origin of Mineral Coal.* It seems to have been principally from vegetation which grew on the spot. Bituminous coals contain about 81 per cent of carbon, and anthracite about 95 per cent. The former contain, in addition, about 5½ per cent of hydrogen and 12½ per cent of oxygen, and anthracite about 2½ per cent of each. Common wood contains 50 per cent of carbon, 6 per cent of hydrogen, and 43 per cent of oxygen. Ordinary coals, therefore, differ from common woody tissue in diminished quantities of hydrogen and oxygen; and this loss is greatest in anthracite. This is the nature of the change which vegetable matter undergoes when immersed in water.

Next, the remains of vegetation are found incorporated in the substance of the coal, and disseminated abundantly through the strata associated with the coal.

Thirdly, beds of peat are coal beds in which the vegetable matter is still in the earlier stages of change, and are evidently coal in process of formation. But we know, from observation, that peat originates from plants growing on or near the place where the peat accumulates.

This explanation is entirely applicable to the formation of coal, since it is shown that vegetation was growing luxuriantly in the places where the coal beds were forming. The character of the vegetation indicates that it grew on low grounds; its preservation from decomposition indicates that standing water was generally present, and the numerous layers of sandy or muddy materials prove that inundations were of frequent occurrence. In proportion as limestones exist, we have proof of deep and lasting inundations by the waters of the oceans. The coal-making areas, therefore, were little elevated above standing water, and were very unstable in their position. They were submerged and barely emergent in comparatively rapid succession.

The carbon in the coal has, therefore, been derived chiefly from the atmosphere. It must have existed there in the form of carbon dioxide. Now, we find that the oxidation of a layer of carbon 2⅛ feet thick over the land would use up all the oxygen in the atmosphere. As the whole amount of carbonaceous material in the earth's crust would make a layer of carbon over three feet deep, it appears that at a time when it existed as carbon dioxide, there must have been in the atmosphere more oxygen than now exists, though it was all combined with carbon, and none existed free for the support of respiration. But the limestones in the earth's crust represent more than 300 times as much carbon dioxide as the coal; and all the carbon dioxide of the post-carboniferous limestones must have existed in the atmosphere along with that which yielded the carbon of the coal. This, as calculation shows, was sufficient to produce a pressure of 224 atmospheres. But a pressure of 80 atmospheres renders carbon dioxide a liquid. It is evident, therefore, that no such amounts of carbon dioxide could have existed in the atmosphere at the epoch of the coal measures, or at any epoch. We must conclude, finally, that the carbon dioxide, represented in the coal and the carbonates of the earth's crust, must have been yielded to the atmosphere progressively, as required. As there is no probability of its derivation from the earth, it seems likely to have been furnished from external space — a conclusion of a very suggestive character.

8. *Growth of the Land during the Upper Carboniferous Age.* The configuration of the land at the beginning of the period of coal formation is shown in Fig. 349. It follows from what has been said of the progressive northward encroachment of the carboniferous deposition in the Illinois basin, and the prevalence of the older coal deposits eastward and the newer westward, that a depression was in progress toward the north, which brought the surface progressively to the low level requisite for coal preservation, accompanied, probably, by a corresponding

elevation in southern Illinois and Kentucky, such as to bring the surface too high for coal-making conditions in the later epochs of the period. (Compare Fig. 318.) Correspondingly, there was a moderate rise along the eastern Appalachian region during the later epochs. Westward, coal-making conditions persisted in Ohio, Indiana, and Illinois, until the concluding stages of the period, when there seems to have been a recurrence of marine conditions in Illinois, Missouri, and Kansas, and farther west a continuance of the marine conditions which had existed during the Lower Carboniferous Age.

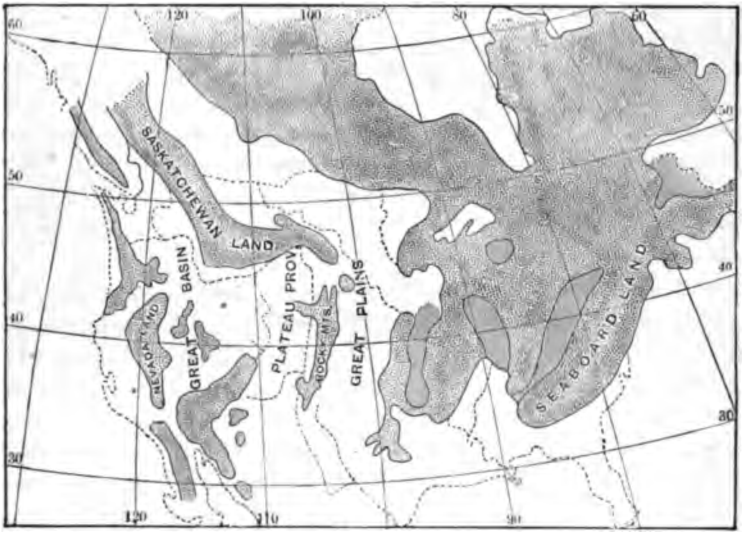


FIG. 349.—MAP OF THE CONTINENT NEAR THE BEGINNING OF THE COAL PERIOD.

§ 8. The Mesozoic Great System.

1. *Divisions, Subdivisions, and Terms.*

III. **Cretaceous System.**

Atlantic Coast.	**Interior.**	**Pacific Coast.**
2. Later Cretaceous.	4. Laramie (Lignitic) Group. [Also in Gulf Region. See § 9.]	Chico Group.
		(Hiatus)
	3. Fox Hills Group.	
1. Earlier Cretaceous.	2. Colorado Group.	Shasta Group.
	1. Dakota Group.	Horsetown Beds. Knoxville Beds.
II. **Jurassic System.**		**Jura-Trias or Red Sandstone Formation of Atlantic Coast.**
2. Flaming Gorge Group.	Atlantosaurus Beds.	
1. White Cliff Group.	Baptanodon Beds.	
I. **Triassic System.**		
2. Star Peak Group.		
1. Koipato Group.		

The Triassic System is so named from its threefold division on the continent of Europe; the Jurassic, from the Jura Mountains, and the Cretaceous, from the presence of great supplies of chalk. The Koipato Group commemorates the Indian name of the West Humboldt Range, formed of rocks of this age. The Star Peak Group is so named by King from the mountain of that name. The Group names for the Jurassic are derived from Flaming Gorge on the Green River in Wyoming, and the White Cliffs of Southern Utah on the border of the Grand Cañon district. The Groups of Interior Cretaceous were named by Meek and Hayden from localities in the Upper Missouri region.

2. *The Triassic System.* Triassic rocks are unknown between the Appalachians and the eastern slopes of the Rocky Mountains. In the eastern province occurs, in numerous isolated patches, a formation long known as Jura-Trias, in consequence of uncertainty as to its age. One of the principal areas occupies the valley of the Connecticut from New Haven to the northern part of Massachusetts. Another stretches from the southern part of New York across northern New Jersey, to the north of

Philadelphia, and west of Washington, into Virginia. Other smaller areas occur in western Connecticut, Virginia, and North and South Carolina. The rocks are largely red sandstones, and in New Jersey and Connecticut are extensively worked for building purposes, furnishing the well known "brown stones" of northern cities. The formation near Richmond, Va., and in the Dan River and Deep River districts of North Carolina embraces, in the middle member, valuable beds of bituminous coal. The coarse limestone breccia known as the *Potomac Marble*, seen near Point of Rocks, Md., and elsewhere, lies at the bottom, and outcrops along the western border of the principal area. The thickness of the formation rises to 3,000 feet.

The eastern Jura-Trias has afforded few organic remains, except foot prints and coal plants. At Portland, and other localities on the Connecticut, the surfaces of many of the layers of the brown sandstone are covered with foot prints of animals, many of which are believed to have been three-toed reptiles, such as are known to have lived, a little later, in New Jersey, and in other parts of the world. (See page 339.) Mammals appeared during this period, and a jaw found in North Carolina has been represented in Fig. 272. The prominent feature of the Age was the commencement of the great expansion of the reptilian type. Fontaine has recently subjected to careful study the coal plants from this formation, and found them to belong to the age of the Lias; and it is quite possible that the whole formation is Jurassic.

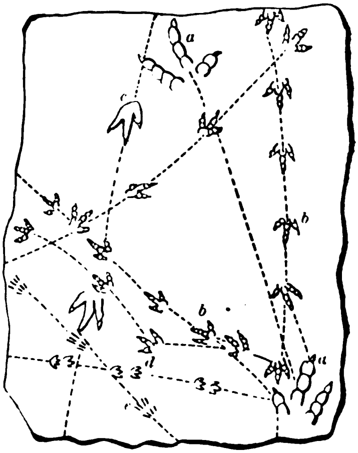


FIG. 350.—SLAB OF SANDSTONE FROM TURNER'S FALLS, WITH TRACKS OF THREE-TOED REPTILES. (E. Hitchcock.) $\times \frac{1}{80}$. (*a*, *a*, $\times \frac{1}{10}$.) *a*, *b*, *c*, Reptilian. *d*, Amphibian.

In the western province,

some beds of sandstones, red marlites, and gypsum outcrop along the eastern slope of the Rocky Mountains (see the Map, page 119), which are either Triassic, or near the bottom of the Jurassic. In the Elk Mountains of western Colorado, Triassic, or Triassico-Jurassic sandstones and marlites, horizontally stratified, make up a thousand feet of the basal portion. Triassic strata form, also, part of the Uinta and Wahsatch Mountains, attaining a thickness of 1,000 to 1,200 feet. In the West Humboldt Range, two groups are recognizable. The lower, or Koipato, consists of a great thickness of quartzose and argillaceous strata, 4,000 to 6,000 feet thick. These, toward the north, become gradually metamorphosed into a porphyroid quite destitute of stratification, and much resembling an erupted felsite porphyry. The upper, or Star Peak Group, consists of a vast series of alternating limestones and quartzites, attaining a thickness of 10,000 feet. The maximum thickness of the Triassic in the West Humboldt Range is, therefore, about 16,000 feet. These two divisions are also recognized in the area east of the Wahsatch Mountains; but no further correlation of strata can be shown. Triassic rocks are also involved in the Sierra Nevada, and extend into eastern California, where they are sometimes auriferous.

The Koipato Group, which is represented by dark red beds east of the Wahsatch, is quite destitute of fossils; while the Star Peak Group abounds in marine forms characteristic of the so called Alpine Trias of Europe.

The Triassico-Jurassic beds of the eastern province rest in long northeasterly trending furrows or depressions between ridges of Eozoic rocks. The latter, not being covered by strata intermediate between the Eozoic and Trias, appear to have constituted a part of the dry land during the Palæozoic ages, as before mentioned, and as shown on all the preceding maps of the continent (Figs. 297, 304, 312, 349). After the Palæozoic, this region, either through subsidence or erosion, or both, became lowered again below sea level in its eastern part. In the West Humboldt basin, similarly, the Trias rests unconformably on the eroded Eozoic and Cambrian strata. But in the Wahsatch-Uinta basin, it rests conformably on the Upper Carboniferous; and the succession of conformable strata is complete downward to the Eozoic, showing that the presence of the ocean was there uninterrupted from very early times. [The small scale of the Map, Fig. 47, renders it impossible to represent the small geological areas.]

A *common* feature of the Triassic everywhere was the eruption of volcanic materials. The trap cliffs of Meriden, Conn.; East and West Rocks, New Haven; the Palisades, on the Hudson; Mt. Tom and Mt. Holyoke, in Massachusetts; Bergen Hill, in New Jersey; the ninety-mile trap dike in southeastern Pennsylvania, Fig. 313, are all features of eruption toward the close of the Triassic Age. Less conspicuous dikes are very numerous. Similarly erupted products are intimately associated with the Trias of the far West; and the same is true of European Trias.

3. *The Jurassic System.* Except so far as indicated in connection with the Jura-Trias of the eastern United States, the Jurassic of North America is confined to the regions west of the Missouri River. The most easterly beds lie along the eastern bases of the Rocky Mountain ranges, and consist of reddish-yellow, friable sandstones, gray, arenaceous marls, reddish-brown bands of clay, and thin bands of cherty limestone, a less compact dolomitic limestone, and thin beds of gypsum. These strata are mostly destitute of fossils; but at Como, fossils are abundant, and fix the age of the formation. The cherty limestone is quite a persistent horizon, and the fossils abound in the marls above and below.

In the Uinta range, in the Flaming Gorge region, the System, as now understood, has a basal, fossiliferous limestone, 200 feet thick, followed by sandstones and shales, 250 feet; a middle limestone, 300 feet, with fossils, followed by clays, shales, and thin sandstones; and at the head of Burnt Fork, a white sandstone is seen at the top of the series. The whole thickness is 750 feet or over.

In the Wahsatch range we have heavy-bedded limestone at the bottom, with a vast series of silicious, argillaceous, and calcareous shales above, the whole rising to 1,800 feet.

In western Nevada, the limestones in the lower part attain a thickness of 1,500 to 2,000 feet, and the shales and slates above, 4,000 feet.

Thus the Jurassic strata, which show a minimum thickness of seventy-five feet at the eastern base of the Colorado range, gradually thicken up to 750 feet in the Uinta, 1,800 feet in the Wahsatch, and 6,000 feet in western Nevada. This is analogous to the change observed in the Palaeozoic strata in passing from the Mississippi to the Appalachians. The direction of the gradation is reversed; but the principle of diminution in volume with recession from the source of the sediments is the same.

The slates of the upper division of the Jurassic extend into eastern California; and on the Mariposa estate, and in neighboring regions, become the gold-bearing formation.

On the southwestern border of the High Plateaus, near the 37th parallel and 113th meridian, the Jurassic consists of a series of bright-red fossiliferous shales, 300 to 500 feet thick, resting on a very massive bed of white sandstone nearly a thousand feet thick.

The fossil remains of the Jurassic are characterized by the relative abundance of the Ammonite group of the Cephalopods (see page 326); by Belemnites, or Cephalopods of the higher order, Dibranchs; by a great increase of Lamellibranchs; by the advent of the modern crinoidal genus *Pentacrinus,* and an enormous development of the class of Reptiles (see page 335). Jurassic Reptiles of gigantic size have been described by Marsh from Morrison and Cañon City, Colo., and from Wyoming.

While the Jurassic is unknown, or at least not certainly isolated, in the eastern United States, it is a widespread formation through all the region between the Black Hills and the Sierra Nevada, and as far south as Arizona; and, for its reptilian remains, is a formation of extraordinary interest. In European geology the Jurassic possesses foremost importance, and admits of three main divisions — Wealden, Oölite, and Lias — with several subdivisions for the Oölite.

4. *The Cretaceous System.* (1) *Distribution and Kinds of Rocks.* The Cretaceous has a moderate development along the Atlantic slope, a larger development in the Gulf States, and covers extensive areas in Texas, and a still wider region over the Great Plains, along the eastern slope of the Rocky Mountains. It is, besides, extensively involved in the general geology of all the interior of the continent, though extensively overlaid by Tertiary strata, as appears from a glance at the Map, Fig. 47. On the Pacific border it occurs in the Coast Ranges; and north of the national boundary it stretches far along the eastern flanks of the Rocky Mountains — perhaps to the Arctic Ocean, and occurs at Vancouver and Queen Charlotte Islands, and at many other points in the interior.

In New Jersey the strata consist, below, of bluish and gray clays, micaceous sand with fossil wood and angiospermous leaves, 130 feet, and above of dark clays, green and ferruginous sands, and yellow limestone, 300 feet or over, making a total of 400 to 500 feet. In Alabama the lowest member, or "Eutaw Group," is a heavy mass of clays, laminated micaceous shales, and irregular layers of green sand, with fragments of dicotyledonous leaves — the whole over 415 feet. Above are eighteen feet of loose and concrete sands with Upper Cretaceous fossils, followed by the "rotten limestone," at least 350 feet, uncemented sand 45 feet, and a white, marly limestone, 6 feet. Total, about 900 feet.

The Cretaceous of the Atlantic and Gulf borders may, therefore, be said to consist of an argillaceous group below, and a calcareous group above. The strata dip gently toward the Atlantic and Gulf, and pass under the Tertiary. The order of superposition in Alabama is shown in Fig. 351. The vertical lines show the positions of selected artesian wells, which are bored in large number, into the lower beds of the System, where the sandy layers carry supplies of pure, sulphuretted or saline water. The Cretaceous here rests directly on the Coal Measures. The Permian, Triassic, and Jurassic must underlie in the region

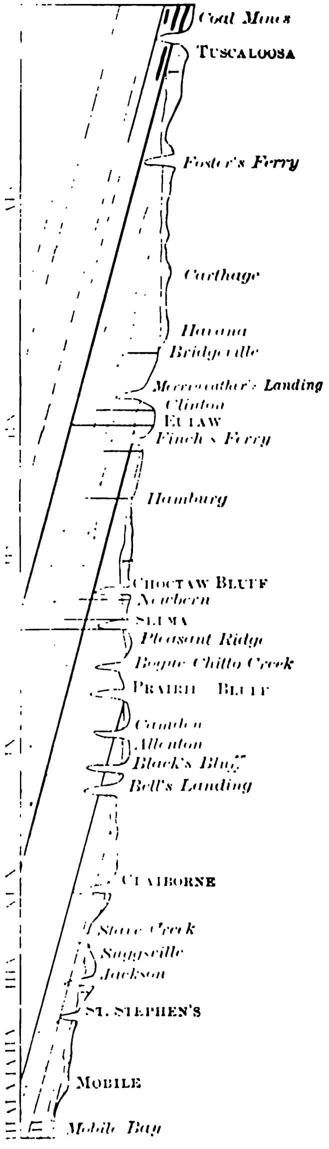


FIG. 371.—SECTION FROM TUSCALOOSA, ALA., TO MOBILE, THROUGH THE CRETACEOUS AND TERTIARY STRATA. I, Superficial Deposits; II–V, Eocene, with its principal [illegible] Tertiary [illegible]; VI–X, Later Cretaceous; XI, Earlier Cretaceous (Eutaw Group); XII, Coal Measures; XIII, Mountain Limestone. The deep excavations show river sections, and the vertical lines artesian wells.

south of the northern limit of the Cretaceous. But it is manifest that a subsidence occurred near the beginning of the Cretaceous, and the sea gained on the land. This is true also on the Atlantic border.

The Cretaceous rocks in Texas consist more generally of solid limestones, showing deeper water and a remoter shore. Tracing the formation northward, we find continued accessions of argillaceous and fragmental matters. In the Upper Missouri region, the lowest member is the coarse Dakota Sandstone, often appearing truly conglomeritic, which comes in abruptly above the calcareous beds of the Jurassic. It spreads westward, southward to the Uinta Mountains and Kansas, and even into New Mexico, increasing in thickness from 400 feet in Dakota to 500 in the Uintas. Next above are the clays and limestones of the Colorado Group, attaining a thickness of 1,700 feet on the Upper Missouri, and 2,000 feet in the Uintas. Then follows the Fox Hills

Group of gray, ferruginous, and yellowish sandstones and arenaceous clays, 500 feet thick above Fort Pierre and along the base of the Big Horn Mountains, and 3,000 to 4,000 feet in the Uintas. Finally, the Laramie Group, attaining a thickness of 2,000 feet, is found very generally from New Mexico far into British America, over a belt 500 miles wide and more than 1,000 miles long. There is evidence that it extends southward even into Mexico. It consists of brackish-water deposits below, and fresh-water above. The rocks are mostly sands, clays, and shales colored with lignitic materials, and containing beds of bituminous or semi-bituminous coal, known as *lignite.* The Laramie contains plants and marine shells resembling Tertiary species found in Europe, and hence some geologists regard it belonging to the Tertiary System. But the Laramie is in some places unconformable with the overlying Tertiary strata, and its land fauna, containing Dinosaurs, was decidedly Mesozoic. Besides, some of the Molluscs possessed Cretaceous characters. Dr. C. A. White has recently shown that the Chico Group of California is probably of this age.

(2) *Economic Products of the Cretaceous.* *Cinnabar* is found in the Coast Ranges of California in minable quantities. The best known localities are New Almaden, 50 miles southwest of San Francisco, and New Idria, in Fresno county.

Gold is found, to a limited extent, in the metamorphic Cretaceous of California, and so are *copper* and *chromic iron;* but none of these are worked. It may be here mentioned, that with the Carboniferous, Triassic and Jurassic, the Cretaceous makes the fourth system of strata found gold bearing in California. The age of the formation, therefore, is not important. It is metamorphism which seems to have separated the metal and gathered it in particles and grains from the rock.

The *Green Sand* common in the Cretaceous of New Jersey is mined as "marl" for fertilizing purposes. The green grains, called also *glau'conite,* contain 8 to 12 per cent of potash and soda, with a trace of phosphate of lime. Some of the limestones of Alabama have recently been found richly phosphatic, as reported by Prof. E. A. Smith, and may prove of great importance to agriculture.

Coal is found to a considerable extent in the Dakota Group, at its very base, in the Uinta region. It occurs, also, on Vancouver Island, in beds referred to the Chico [Chee′co] Group of California, which is Upper Cretaceous — in the position of the Colorado Group of the Upper Missouri. In California coal is produced from the Téjon [Ta′-hon] Group in the Coast Ranges, and this has been considered to hold the place of the Laramie Group of the Interior; but Dr. White, in a recent memoir, has shown it to be of Eocene age. Back from Se-at′tle on Puget Sound, Washington Territory, coal of excellent quality is mined. Ten miles from Se-at′tle is the so called Renten coal; at twenty miles, the Newcastle coal, of better quality; and at 30 to 40 miles back, on Cedar River, is the Coleman coal, of still superior quality, obtained in a bed reported 40 feet thick. Still farther back, in the Foot Hills of the Cascade Mountains, is said to occur the best of all; but this is not yet opened.

The coal supplies of the Cretaceous possess very great importance, since the coal is of good quality, and is widely distributed through regions not supplied with Palæozoic coal. The Vancouver and Washington coals are shipped to San Francisco and the Hawaiian Islands. The Laramie Group coal is widely employed in Utah at Evanston and Coalville; in Wyoming, at Carbon and Hallville, at Black Butte Station on Bitter Creek and Bear River, and in the Uinta basin; in Colorado, at Denver, Golden City, and other localities; in New Mexico, at the Old Placer Mines, in the San Lazaro Mountains. The bed at Evanston is 26 feet thick, containing 37 38 per cent of volatile substances, and 49 50 per cent of carbon. The Wyoming coal is shipped eastward as far as Omaha. At the Old Placer Mines the rocks are upturned and metamorphic, as in eastern Pennsylvania, and the coal, accordingly, is partially debitumenized — containing from 68 to 91 per cent of fixed carbon. This is of Laramie age, and lies in the Trinidad Coal Field of Stevenson, which stretches along the eastern base of the Rocky Mountains, lying partly in Colorado and partly in New Mexico.

Productive coal measures occur in the Cretaceous on the coasts of the islands and main land north of Victoria, British America, at Maple Bar. At Nanaimo, Departure Bay, extensive mines of Laramie age; also at Comox, an extensive field not worked. Coal partly anthracite, associated with plants having Jurassico-Cretaceous affinities, according to Dawson, has been recently reported from Old Man River, Martin Creek, and one other locality farther northwest, on the Suakwa River. Coal outcrops are reported from the Lower Cretaceous, on the line of the Canada Pacific Railway, at the crossing of the South Saskatchewan, and at Bantry; and from the Laramie at Bassano, Crowfoot, and Coal Creek (long. 114° 35′).

The Cretaceous, therefore, is a great coal-producing System, perhaps not inferior in importance to the Carboniferous. Since it produces no chalk in America, its name appears to be doubly a misnomer.

(3,) *Fossil Remains of the Cretaceous.* The Brachiopods are reduced mostly to the *Terebratula Family.* The Lamellibranchs increase in numbers and diversification, and approach decidedly toward modern types. The Oyster family is largely developed. Some oysters (*Gryphæa mutabilis*) were seven inches in diameter in Alabama, and other species (*Exogyra costata*) were five inches across; while *Ostrea larva* presented a strikingly falcate form, with a deeply and acutely sinuate border. The Ammonite family continued to increase in importance (see the notice, page 326), but completely disappeared at the close of the Cretaceous. The higher order of Cephalopods, Dibranchs, continued to increase. The family of Belemnites was largely represented. The Belemnite resembled a modern squid, but its internal bone, or osselet, was prolonged behind in a cone called the *pen.* This had a longitudinal cavity (*alveolus*) opening forward, and having at its posterior end a chambered cone called the *phragmocone,* which had a siphuncle. The ink bag was contained within the cavity of the osselet.

A highly characteristic reptile of the Cretaceous was the *Mosasaurus*, described page 338, whose vertebræ are common in the Upper Cretaceous of the Gulf region. This was an age of sharks, both Squalodonts and Cestracionts. Their teeth lie scattered abundantly over the exposed Cretaceous surfaces of Alabama and Mississippi—by the roadsides, in the fields, and along the river margins. Teleost fishes, or those of the modern type, became quite abundant. Plants of modern dicotyledonous genera prevailed in the forests, besides many modern forms of monocotyledons. On the whole, the dawn of the modern aspects of the world was evidently near.

5. *The Physiognomy of the Interior of the Continent.* The Mesozoic strata enter so largely into the formation of the whole Interior that we turn for a moment to a general consideration of its physiognomy. After passing the "Province of the Great Plains," which stretch westward from the Missouri River," we reach the first Ranges of the Rocky mountains proper — the Colorado and Laramie Ranges — the former also known as the Front Range. These are succeeded at intervals of 30 or 40 miles by the Medicine Bow and Park Ranges, and the Sahwatch Mountains. These are broad massive ranges, serrated with lofty snow covered peaks, and trending approximately north and south. The valleys between them are fertile expanses known as "Parks," like "North," "Middle," and "South" Parks. Their snows form a perennial reservoir for streams flowing, on one side, into the Gulf of Mexico, and, on the other, into the Gulf of California. These mountains are sometimes known collectively as the Park Mountains; and the whole zone forms the "Park Province." It may be regarded as extending to the 107th meridian.

West of this comes the "Plateau Province," a broad elevated expanse broken by faults, cut by gorges, wasted by denudations, and dotted with innumerable volcanic outbursts, lone mountains and groups of mountains, and short ranges. It is drained by the Colorado River of the West and its tributaries. It stands on an average 5,000 to 7,000 feet above the sea. Its mountain features, of which the Uinta constitutes the northern boundary, trend east and west. Southward, the Plateau Province stretches into Arizona. It terminates westward with the Wahsatch Mountains, a north and south range which has been split longitudinally by a great fault, on the west of which the mountain and the whole country has been sunken six to seven thousand feet.

The steep westerly front of the Wahsatch Range overlooks the next province. It is called the "Great Basin," or "Basin Province." It is 500 miles wide, stretching to the Sierra Nevada, and stands generally at a level lower than that of the Plateau Province. It is characterized by a large number — probably over 150 — of short mountain ranges, which trend north and south. Some of these, in order westward, are the Gosiute, Pequot, East Humboldt, Piñon, Cortez, Shoshoni, West Humboldt, and Montezuma ranges. The Union Pacific Railroad passes the northerly extremities of these. On the south are numerous other short, meridional ranges, continuing at least as far as the 37th degree of latitude. These are known as "Basin Ranges." The drainage of the Basin Province is mostly toward interior salt lakes.

The Basin Province is bounded by the Sierra Nevada, another great mountain range split longitudinally along its crest, with the eastern half let down 3,000 to 10,000 feet. The steep eastern face of the Sierra Nevada overlooks the Great Basin toward the east, as the Wahsatch faces it toward the west. From the summit of the Sierra Nevada the country slopes generally toward the Pacific, and forms the "Pacific Province." The Coast Ranges of California, however, interrupt the slope, and cause a longitudinal valley along the centre of the state, stretching from Mt. Shasta, on the north, to far beyond Tulare Lake on the south. From the north along this valley flows the Sacramento River; and from the south the San Joaquin. The two bend westward on the 38th parallel, and find exit through the Coast Ranges into the Bay of San Francisco.

The name Rocky Mountains is by some employed to embrace all the mountains from the Colorado Range to the Sierra Nevada. But this seems objectionable. The breadth of country is more than a thousand miles. The mountain features are not conformable to one plan; they do not constitute one system; they were uplifted at various geologic epochs; they are separated by broad intervals; they are formed of rocks of various ages. We may designate as Cordilleras, after Humboldt, the entire assemblage of mountains, and restrict the name "Rocky Mountains" to the Park Ranges along the eastern border. These constitute the dividing ridge between the waters flowing into the Mississippi and those flowing into the Pacific.

6. *Comparative Geology of the Provinces.* The central masses of the Park Mountains are of Eozoic strata, and are enwrapped, often unconformably, by Palæozoic formations. All these are involved in the disturbances of the primitive upheavals. Mesozoic and Cænozoic formations abut against the uplifted slopes, and have been themselves tilted by later upheavals, and extensively wasted by denudation. (See the section, Fig. 352.) The old nuclei were extensively plicated with closely appressed folds prior to the deposition of the later sediments. The Park Mountains stood as long islands in the midst of the ocean of Mesozoic and Cænozoic times. This stretched from beyond the Wahsatch Mountains eastward. It covered the whole of the Plateau Province till late in Cænozoic time, and continued to receive the sediments contributed from the ancient continent farther west. The Plateau Province is almost wholly underlaid by post-Palæozoic strata, though in places upheaval and erosion bring Carboniferous strata into view. The Basin Province, now so depressed, was, till Cænozoic time, the most elevated region of the Interior. It is underlaid by Eozoic and Palæozoic rocks, with some Mesozoic and Cænozoic in the Humboldt Mountain district. It was mostly, during Mesozoic and Cænozoic time, a continental mass, with drainage eastward into the ocean of the Plateau Province. It supplied the sediments which overspread its bottom, and was wasted by the service. Finally, in late Tertiary time, the Plateau region was raised above the level of this ancient land, and the Park region was elevated still higher. Thus the direction of the drainage was reversed.

The uplift of the Great Plateau was accompanied by an extensive system of faults, which rent the Plateau Province from north to south. The huge resulting prismoids present the various attitudes and mutual relations which have been described as Kaibab structure, Uinta structure, and monoclines (page 160). These features are illustrated in Figs. 85, 86, and 87. Volcanic outflows have contributed to further modify the surface, forming sometimes mountain saliences above the plateau, and sometimes broad sheets on which erosion has subsequently acted, cutting slit-like gorges and carving high mesas, which rise like titanic tables here and there over the scarred and desert expanse. Some of the most important volcanic mountains in this Province are Pilot Butte, the Uinkarets, and San Francisco Mountain. Here also are the mountains of the laccolitic type, like the Henry, the Navajo, and Sierra la Sal (see page 157). In southern Utah the Cænozoic and Mesozoic formations terminate in a succession of gigantic steps descending toward the Colorado River, whose "Grand Cañon" cuts five and six thousand feet deeper into Palæozoic and Eozoic rocks. The cañon features are illustrated in Fig. 31; and a bird's-eye view of the southern part of the Plateau Province is shown in Fig. 87.

7. *Geological History of the Cordilleran Region.* It will be remembered that the Cordilleran wing of the continent at the end of Eozoic time stretched in width from the Nevada region eastward to the 104th meridian; and that it then began to sink, and continued sinking during the entire progress of Palæozoic time, so that finally only the highest peaks rose through the mantle of sediments. The Cordilleran ocean was now, as it had long been, an archipelago; and the vast

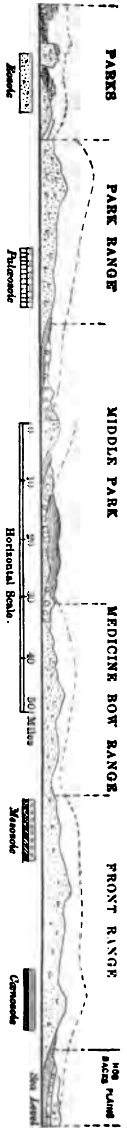


FIG. 352.—GENERALIZED STRUCTURE SECTION ACROSS THE PARK PROVINCE.

series of Palæozoic sediments, covering the ancient continent unconformably, were entirely conformable among themselves — a state of things quite unlike the frequently occurring unconformabilities east of the Mississippi.

Widespread mechanical disturbances now occurred. The land area west of the Nevada Palæozoic shore became depressed, while all the thickest part of the Palæozoic deposits from the Nevada shore, eastward to and including the Wahsatch, rose above the ocean and became a land area (King). Between the new continent and the old one which went down, to the west, there was a complete change of condition. The land became ocean, the ocean became land. The new land extended eastward to include the Wahsatch. Eastward of that, to the Great Plains, and including them, the former ocean bed remained undisturbed. The new-made land, from the Wahsatch to 117° 30′ west, now yielded the sediments destined to form all the post-Carboniferous formations. That is, the Basin Province was then the continent, and eastward stretched a vast mediterranean sea, as far as Kansas and Nebraska, and southward to the Gulf of Mexico, and northward probably to the Arctic Ocean. (Compare the map of America at this epoch, Fig. 353.) West of the new land mass of the Basin Province, the successive deposits of the Triassic and Jurassic Ages were laid down in conformable sheets of enormous thickness, directly but unconformably upon the ancient Eozoic floor. East of the same land mass, the Triassic and Jurassic sediments rested conformably on the top of the Carboniferous. West of the Basin-Province Land, over the Sierra Nevada belt and California, the Mesozoic sediments attained a thickness, by the close of Jurassic time, of 20,000 feet; in the mediterranean sea, a thickness of only 3,800 feet. The western sea was deep; the mediterranean was shallow.

At the close of the Jurassic Age, the western ocean, with its original floor of Eozoic ranges, overlaid by twenty odd thousand feet of Jura-Trias sediments, suffered abrupt orographical uplift, resulting in the sharply folded ranges of the Sierra Nevada, and extending the continent 200 miles further west. This uplift stretched southward as far as the 36th parallel, and northward probably to Alaska. East of the Wahsatch, however, everything remained undisturbed. The earliest sediments of the Cretaceous were laid down conformably over the Jurassic. But the great event which had marked the history of the Basin and Nevada provinces was signalized over the Plateau and Park provinces by an invasion of coarse and even conglomeritic deposits. These constitute the Dakotah Group of the Cretaceous. They stretch from the Wahsatch into Kansas. They covered the entire bottom of the mediterranean sea; that is, the entire Province, with the exception of a few Eozoic islands which, from the time of the Cambrian, had stood above the plane of deposition. This physical condition of things continued through the Cretaceous. The greatest thickness attained by deposits of this Age was along the western border of the ocean, where we find about 12,000 feet of Cretaceous. Passing eastward, the thickness diminishes. Along the eastern base of the Rocky Mountains, we find it thinned to

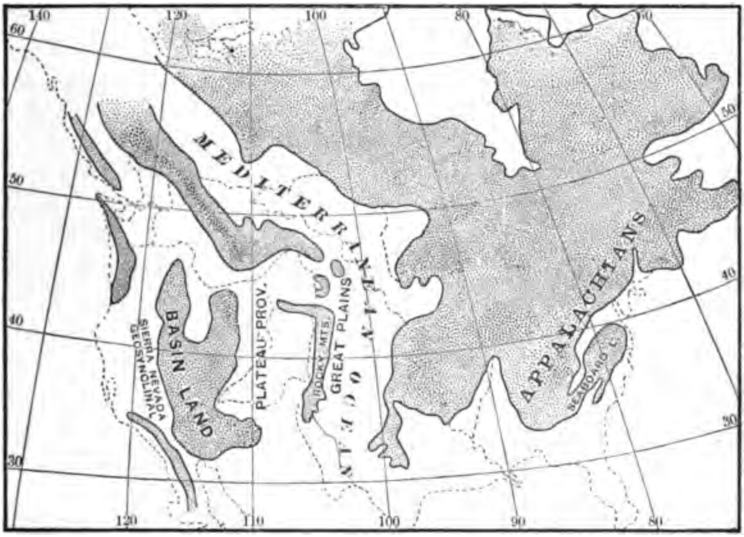


FIG. 353.—NORTH AMERICA, NEAR THE BEGINNING OF THE MESOZOIC ÆON.

1. EOCENE GROUP.
   (4) Uinta Formation.
   (Brown's Creek, Powell),
   (3) Bridger Formation,
   (2) Wahsatch Formation,
   (c Vermillion Creek, King. or Bitter Creek, Powell),
   (b) Green River Division
   (? Elko Group, King),
   (a) Wahsatch Division,
   (1) Puerco Formation of Cope.

ALABAMA GROUP.	Vicksburg, 175? ft.,	White Limestone (Oligocene).		
	Jackson, 60 ft.,			
	Claiborne, 150 ft.,	Claiborne	Calcareous,	Eocene.
	Buhrstone, 175-200,		Silicious,	

The Téjon Group, California, is Eocene.

Lignitic, 1,000 ft.,	Bluff Lignite,	Cretaceous.
	Orange Sand, or La Grange,	
	Porter's Creek,	

The terms, "Tertiary and "Quaternary" are survivals of an old system of nomenclature in which "Secondary" was nearly equivalent to our "Mesozoic," and "Primary" had a somewhat undefined range over rocks older than "Secondary." "Eocene," "Miocene," and "Pliocene," introduced by Lyell, are from Greek terms, signifying "Dawn of the Recent," "Less Recent," and "More Recent." Some include the upper part of the Eocene, and the lower of the Miocene, in another group, "Oligocene," which signifies "slightly recent." The Miocene and Pliocene, taken together, are sometimes designated "Neocene," signifying "newer recent." The subdivisions of the Tertiary groups are designated by geographical terms. Those most distinctly limited belong to the Great Plains and the Cordilleran region. The Puerco, though generally regarded as embraced in the Wahsatch, is urged by Cope, with good reasons, as a coördinate group below the Wahsatch. The terms employed for the divisions of the Quaternary refer to the physical conditions prevailing — except "Champlain," which alludes to the basin of the lake of that name.

2. *Geographical Distribution of the Tertiary.* The Tertiary strata accessible to study embrace only the limited areas which have been raised above water level, or otherwise drained, since the close of Mesozoic time. They are, therefore, of comparatively small extent, and partly in detached interior regions. A belt of marine Tertiary strata extends from Martha's Vineyard over Long Island, southern New Jersey and the Atlantic coast to Key

West, and thence around the Gulf border into Mexico. It gradually increases in width to Florida, attaining in Georgia a breadth of 245 miles. In the valley of the Mississippi it spreads out in a deltoid form, reaching, with its apex, to the mouth of the Ohio. A belt of marine Tertiary stretches along the Pacific coast, forming, with the Cretaceous, the Coast Ranges of mountains. Several detached but extensive areas of fresh-water Tertiary occur in the Interior. The Great Plains, up to the bases of the Rocky Mountains, and southward to the Gulf of Mexico, are covered with lacustrine Tertiary, chiefly of Pliocene age, at surface. Another Pliocene basin exists in Nevada, and a third in the North Park. A great basin stretching from the Colorado, or Front Range westward to the Wahsatch is of Eozene age. Northwest it extends to the Wind River Mountains, over the so called Green River Basin, and southward it stretches into New Mexico. Over part of the eastern slope of the Rocky Mountains, along the valley of the White River, are Tertiary deposits of Miocene age, underlying the Pliocene; and others spread through central Oregon along the John Day River. The Eocene beds of the Cordilleran region attain a thickness of 10,000 feet. The Puerco of Cope, which perhaps is not included in the estimate, extends from the sources of the Puerco River in New Mexico, northward and a little east of the Wahsatch Mountains, consisting of green and gray marls, 500 to 1,200 feet thick. *Coryph'-odon* and other mammals of the Wahsatch group are wanting; but Marsh subordinates the Puerco to the Wahsatch.

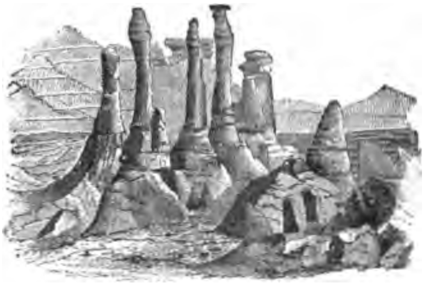


FIG. 355.—VIEW IN THE BAD LANDS OF NEW MEXICO. (Cope.)

The Tertiary strata are generally little coherent. They have consequently been worn by rains into deep ravines, and fluted slopes, and isolated columns. Such areas being destitute of verdure and soil, are known as *mauvaises terres*, or "bad lands"—a designation first applied to a portion of the White River region. A view in one of these Bad Lands in New Mexico is given in Fig. 355.

3. *Organic Remains of the Tertiary.* The three great divisions of the Tertiary are based on the percentage of molluscan species belonging to the recent fauna. In the Eocene the percentage of recent species is small; in the Miocene, less than half, and in the Pliocene, more than half. Generally, however, the aspect of the molluscan fauna was decidedly modern. It contained few Brachiopods, numerous Lamellibranchs and Gasteropods, and no chambered shells except Nautilus. Sharks of the Squalodont type were very abundant; and Teleost Fishes prevailed as in modern seas. The remains of the latter are of very frequent occurrence in the Green River Shales, in the upper part of the Wahsatch formation.

The great feature of the organic life of the Tertiary, however, was its Mammals. Dugongs and Whales abounded in the sea. *Zeuglodon*, a whale-like mammal with an attenuated posterior part, attaining a length of over 70 feet, has left its bones in the White Limestone of the Eocene of the Gulf States. Vertebræ of whales are found at Gay Head on Martha's Vineyard, together with the teeth of Squaloids.

The land Mammals, which were far more important, have been already noticed as far as space permits on pages 348–358, which the student should now review.

4. *Quaternary Materials.* Here we return to the point from which we started on entrance upon this study. In Part I, Studies I–III, attention was directed to the materials of the Drift, and their method of arrangement. These Studies should be now reviewed. The principal object of the next eleven Studies (IV–XIV) was to become acquainted with the materials of the Drift. In Studies XV and XVI we also considered phenomena of the Drift. Thus the simple observation of things nearest at hand led our thoughts to operations performed many ages before man existed on the earth—operations of erosion and sedimentation

which have contributed so greatly to form the vast rock masses, and sculpture the terrestrial surface into the forms which it presents to our eyes. In this place, therefore, we have only to refer to what has been said, and add a few statements of facts not so easily observed.

(1) *Phenomena of the Surface Materials.* A line having a general westerly direction from Sandy Hook through Cincinnati marks the southern limit of bowlders. From Cincinnati it continues to the parallel of 38° in southern Illinois and Missouri; but west of the Missouri River it trends in a direction parallel with the river into Dakota. The incoherent surface materials on the south of this line differ in several respects from such materials on the north of it. (*a*) On the south there are drifted materials, as well as on the north, but bowlders larger than pebbles are wanting. (*b*) On the north we notice a distinction of unstratified Drift, semi-stratified Drift, and stratified Drift. The first consists of clay with imbedded bowlders, lying generally on the bed rock, but often outcropping at the surface. The second consists of sand, clay, pebbles, and a few larger bowlders, showing oblique and irregular lamination, and holding position above the *till* or unstratified Drift. This has evidently been moved and laid down by powerful and irregular currents of water. The stratified Drift is composed of horizontal beds of fine materials, mostly along the borders of lakes, or in situations from which lakes have disappeared. It appears to be the result of lacustrine action, and is thus a "*lacustrine* formation." Its position is above the semi-stratified Drift. Another form of obscurely stratified materials occurs sometimes along river valleys. It is fine, loamy, buffish, and calcareous, with occasional remains of vegetation and land animals. It is known as *löss*, a German term. It may be seen on the Mississippi River at Vicksburg, Memphis, and Davenport; on the Des Moines at Des Moines, and on the Missouri at Council Bluffs and Omaha. We find, also, fluviatile deposits of recent origin. The term Drift, as ordinarily employed, is not understood to embrace the lacustrine, löss, and fluviatile deposits, though they are all mostly modifications of Drift. On the

south of the boundary line named, the unstratified Drift is wanting; but semi-stratified Drift is generally present, together with occasional lacustrine, and more abundant fluviatile and löss deposits.

(c) On the north of the boundary line the Drift materials extend downward to the bed rock, and end abruptly on a solid, but sometimes shattered, rock surface. The solid surface is generally smoothed and marked by grooves and striæ. On the south, the obliquely laminated Drift near the surface mingles gradually with materials resulting from the disintegration of the rock immediately underlying, until the latter materials predominate; traces of the original stratification appear; the substance grows less and less changed, and passes downward by degrees into sound, unaltered bed rock. That is, in the south the lower part of the surface deposits seems to have resulted from the decay of the underlying strata, and we can trace the stratification upward from the unaltered rock into the overlying, unconsolidated beds. These lower portions *have been formed where they lie;* only the higher, gravelly portions have been brought from some other region. The lower portions, therefore, are not properly any part of the Drift. The upper, transported sand and gravel are much less abundant than the proper Drift of the North; but yet, in some localities, they are found one or two hundred feet thick.

(2) *Relation of Drift Phenomena to Climatic Causes.* It thus appears that the geological action which in the north removed the decayed rock, smoothed and striated the general rock surface, and distributed the bowlders, ceased to operate in about the latitude of Cincinnati. It was an action correlated to climate, since the differences are latitudinal, and the separating line, in mountain regions, is deflected southward, like an isotherm.

The smooth and striated condition of the bed rocks throughout the northern states (see Figs. 200 and 213) is a condition such as is produced in modern times in all glacier-covered regions (pages 280-281); the transportation of bowlders is a phenomenon of glacier action; and thus the two most characteristic features of the Drift are traceable, not only to climatic, but to glacial causes.

Again, the deposition of the semi-stratified Drift appears to have resulted from some torrential action, such as might be caused by the rapid conversion of ice into water. Thus, while striæ and bowlders are phenomena which suggest a geological winter, modified Drift is a phenomenon suggesting a geological springtime. Comparing the North and South, we see that the ice of the geological winter did not pass the parallel of 39°; the floods of the geological springtime rushed to the Gulf of Mexico.

(3) *More Critical Observation of the Drift.* Now that we plainly see reasons to regard the Drift as the result of glacier action, much light is shed on the nature of other phenomena. The broad sheet of commingled clay, sand, gravel, and bowlders firmly compacted together, lying immediately on the rock floor, may be regarded as *Subglacial Till* laid down beneath the thinning marginal portion of the ice sheet. The sheet in some places overlying this, similar in character, but less compact, is *Englacial* or *Superglacial Till*, formed of materials imbedded in the ice, or accumulated on its surface; while the more homogeneous till, with occasional traces of stratification, and holding a higher position, is *Subaqueous* or *Floe Till*, formed under water through the agency of floating ice. (Chamberlin.)

In the modified Drift we make (following Chamberlin) the following discriminations: The long narrow, sharp ridges of gravel and sand, with some bowlders, stretching out from higher to lower levels, and following generally the courses of the larger valleys, are *Osars*. The assemblages of conical hills and short, irregular ridges, with intervening depressions and bowl-shaped hollows, are *Kames* (Fig. 5). Unlike the osars, they tend rather to stand transverse to the slope of the surface, and to the direction of the glacier movement.

Among phenomena connected with glacier action, we discriminate *lateral*, *median*, *interlobate*, and *terminal moraines.* Lateral moraines are accumulated along the borders of a glacier (Fig. 211); median result from the union of two contiguous lateral moraines, where two glaciers become confluent; interlobate moraines result from the joint action of two adjacent glacier lobes or tongues, which push their contiguous lateral moraines together without becoming properly one glacier stream. A terminal moraine accumulates in front of the glacier, so that when the glacier retreats, the moraine remains as a curved ridge of confused or locally stratified materials. (See Figs. 211, 212.)

(4) *The Terminal Moraine of the Ancient Glacier.* The continental glacier of the United States must not be conceived as one continuous sheet of ice, moving forward with equal pace in all its parts, and accumulating a rigidly continuous moraine, stretching along an unbroken glacier front. The great glacier suited itself to the topographical configuration of the land. It must be viewed as a viscid fluid pursuing the courses of the great valleys, and protruding its front in irregular lobes, in varying directions and to varying distances, according to the direction and length of the valley axes. On the general retreat of the great glacier, therefore, the continental moraine would consist of a series of crescentic ridges more or less disconnected. So we find it.

But we must now remark that the glacial period in North America, as in Europe, appears to have been divided into two or more epochs, separated by one or more interglacial epochs. Evidences of such division have been detected in so called "dirt beds" in Illinois and elsewhere, intercalated in the glacial Drift. Indications of similar purport are found in New Jersey. We have, accordingly, the phenomena of two or more glacier terminations. The older epoch was marked by a glacier which had for its southern limit the line which has already been traced, and which is shown in detail in Fig. 356. The newer epoch appears to have been marked by a glacier leaving, generally, a more northern moraine. Both moraines have recently been traced across the whole extent of the country from Cape Cod to Dakota. For this work we are indebted chiefly to Messrs. Lewis and Wright for the Atlantic seaboard, Chamberlin for the Interior, Upham for Minnesota, and Wooster for Dakota. Professor Wright's investigations extended also into Indiana, and Chamberlin's stretched from New Jersey to Dakota. The aggregate results possess extreme interest, and are mapped on a small scale in Fig. 356.

A glance at this map shows a line of morainic crescents extending from Cape Cod along or near the southern boundary of the Drift area, to Indianapolis. This is generally regarded as a line of vestiges of the terminal moraine of the earlier glacier. The more northern morainic system is supposed to pertain to the second glacier. It is impracticable here to enter into any detailed description of these moraines. We direct attention simply to a few points. (*a*) The older moraine does not border the Drift-covered area west of Indiana. (*b*) It is not coincident with that border west of Pennsylvania. (*c*) From western Pennsylvania to Michigan the second morainic system is either wanting or coincident with the first moraine, or quite overlapped it and obliterated it. (*d*) West of Lake Erie the second moraine consists of a series of great loops rudely concentric with the great lakes and their principal bays. It may be added that the directions of the glacial striations on the rocks indicate that each of these principal and subordinate basins had its separate glacier sheet, which formed its separate loop in the moraine system. (*e*) The

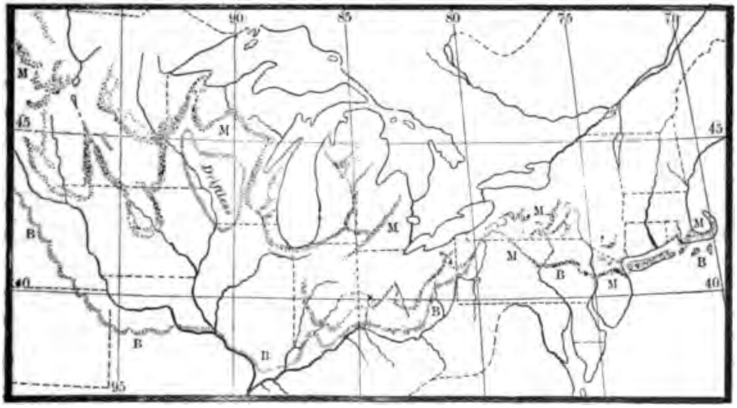


FIG. 356.—MAP OF TERMINAL MORAINE TRACED ACROSS THE UNITED STATES. (From Chamberlin's Report.) *B*, *B*, *B*, Southern Limit of Drift; *M*, *M*, *M*, Moraines.

remarkable northwesterly trend of the moraine in the valley of the Missouri River follows the isothermal lines. (*f*) A broad, driftless area is shown in Wisconsin. (*g*) Two state universities are located on the second terminal moraine. The University of Minnesota is located near the junction of the eastern Lake Superior and northern Minnesota moraine. The University of Michigan is on the interlobate moraine, between the Saginaw and Maumee glacial lobes—the Kames rising 300 and 400 feet above the bed rock, and the "cat hole" within the city limits of Ann Arbor being one of the morainic "kettles."

(5) *Characteristics of the Terminal Moraine.* The Terminal Moraine, or more specifically the Second Moraine, consists of an extensive irregular range of confusedly heaped drift ridges or knolls. It sometimes consists of two or more separate ranges, which occupy a width of 20 to 30 miles, while each range is from one to six miles wide. The morainic range is constituted of a series of hills of rapidly but gracefully undulating contour, with rounded domes, conical peaks, winding and occasionally geniculated ridges, short, sharp spurs, mounds, knolls, and hummocks promiscuously arranged, accompanied by corresponding depressions. The latter are variously known as "potash kettles," "pot holes," "pots and kettles," "cups and saucers" (Fig. 7), "sinks," etc. The characters are shown in the accompanying view of the moraine near Eagle, Wis. (Fig. 357). These characters are not fundamentally different from those presented by the general Drift. They are much more pronounced, and are ranged according to a discoverable system.

Internally, the moraine is distinguishable into two portions. The one, usually the uppermost, but not occupying the heights of the range, consists almost wholly of assorted and stratified material, resembling the modified Drift under its usual and familiar aspects (Fig. 7). The other element of the moraine constitutes its basal and central portion, and consists of a confused commingling of clay, sand, gravel, and bowlders, often resembling true subglacial till. It is probably true till pushed up by the glacier, acted on and locally assorted and stratified by waters escaping from the glacier.

(6) *Tabular Limestone Masses Imbedded in the Drift.* In certain regions — notably southern Michigan, in the counties of Washtenaw, Lenawee, Hillsdale, and Jackson, and also in Berrien, Van Buren, and Ottawa — occur numerous tabular masses of limestone, some of which attain dimensions of 10 to 20 feet square with a thickness of one or two feet, and supply material for numerous limekilns of a transient character. These masses occupy nearly horizontal positions, and lie imbedded near the summits of knolls of semistratified sand. They are fragments of Corniferous Limestone, as the fossils prove, the nearest outcrops of which on the north are at Mackinac, and on the south within the distance of 10 to 30 miles. They have not the worn aspect of bowlders; they have been transported gently. The presumption is that they have been derived from the south. The present writer suggested, some years ago, that they were floated by ice floes formed over shallow lakes accumulated in front of the glacier during the period of retreat. Chamberlin, on the contrary, has suggested that they were plowed up and transported by the glacier, and made part of the terminal moraine. Similar frag-

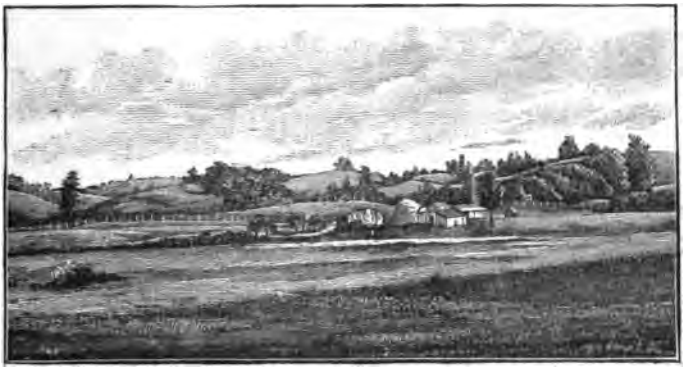


FIG. 357.—WESTERN FACE OF THE MORAINE NEAR EAGLE, WIS. (Chamberlin.) Compare also Fig. 5.

ments are reported from Wisconsin. The explanation of these exceptional facts is still to be sought.

(7) *Champlain Deposits.* These consist chiefly of the incoherent stratified materials bordering certain lakes. They are well shown about the western end and northern border of Lake Erie, whence they have been named the "Erie clays." They occur also over the western part of the peninsula of Ontario, stretching into Michigan. They consist of layers of clay and sand mingled with some vegetable matter, and ascend the bordering slopes sometimes to the height of one or two hundred feet. The lower sandy layers rising to the surface become saturated with rain water, which is borne along the dip of the stratum, and thus furnishes supplies of artesian water to localities at the lower levels.

Other extensive Champlain deposits are found in the valley of the Red River of the North. They were laid down in a former great lake, which Mr. Warren Upham proposes to call Lake Agassiz. The shore lines may still be traced at various levels on the east and west. The lake must have received the waters of the Saskatchewan, and had its outflow southward to the Mississippi.

Evidently the sediments bordering Lakes Erie and Michigan were laid down when the lakes stood at higher levels. As to the drainage and diminution of lakes, it seems to have been general. The climate of America has grown dryer in late geological epochs. But undoubtedly much lake drainage has resulted from a wearing down of outlets. Apparently this cause has operated upon Lakes Erie, Huron, and Michigan, as was explained when treating of the Niagara gorge. Fig. 305 may now be further studied.

(8) *Quaternary Lakes.* In the Basin Province of the Far West we find the remnants of ancient Quaternary lakes, which far exceeded present limits. Their former bounds are shown by old beach lines. These lakes — of which Lahontan and Bonneville are best known, thanks to the labors of Gilbert and King — resulted originally from the subsidence of the east and west sides of the Basin, which took place at the end of the Pliocene. The

bottoms of the depressions formed were 4,000 feet above sea level, and their borders 5,000 feet. Vestiges of Lake Bonneville are seen at present in Great Salt Lake, Utah Lake, and Sevier Lake. This lake was 300 miles long and 180 miles broad. The highest terrace is 940 feet above the present level of Great Salt Lake. Lake Lahontan lay in western Nevada, along the bold front of the Sierra, and was nearly as large as the former; but it was much cut up by mountain ranges. Remnants of this lake are still seen in Pyramid, Winnemuca, Carson, Walker, and Humboldt Lakes. These great ancient lakes began to exist with the beginning of Quaternary time — though Lahontan was a smaller lake during the Miocene — but the progress of their desiccation continued into the Champlain epoch; and some evidences exist that it continued till near the present. The water of Great Salt Lake, however, rose eleven feet between 1849 and 1878. But it was nearly constant till 1866, and the rise is a later occurrence. King is of the opinion that the salinity of these lakes is derived from the influx of saline waters. If, as Gilbert and King have shown, they formerly had drainage to the sea, their primitive salinity derived from the influx of ocean water must have been exhausted; they were fresh-water lakes during their high level; and since the outflow ceased, the only probable source of their present salinity is the slight saline contribution brought by tributary streams. Though these lakes are generally considered coeval with eastern glaciation, it remains to show, with plausibility, that they were not rather a feature of the Champlain Epoch.

In the northwestern part of the Great Basin, in Oregon, other Quaternary lakes have been described by Russell. These occupied the sites of the present lakes, Alvord, Malheur, Warner, Guano, Summer, Abert, Silver, Goose, and Klamath, in Oregon, together with Surprise Valley and the Madeline Plains in California, and Long Valley in Nevada. Some of them attained a depth of 500 and 600 feet, and spread far beyond the limits of the modern lakes. In the old bed of Christmas Lake are found many modern species of fresh-water shells, together with bones of mammals reported by Marsh as Pliocene,— and thus possibly washed in after fossilization. These lakes lie between the 117th and 121st meridians, and extend from the parallel 41° to 43° 30′. Directly north of this group of lakes, between the parallels of 46° and 47° 30′, is the bed of another ancient lake, designated Lake Lewis by Lieutenant Symonds, who regards the lake as of Champlain age.

(9) *Recent Formations.* River terraces and some other phenomena of the latest epoch of geological history have been sufficiently considered in Part I, Study XV. River terraces are illustrated in Fig. 210.

The geological work of the Recent or Terrace Epoch embraces much more than the formation of terraces, as commonly understood. Since the dissolution of the continental glaciers, the drainage of the land has become settled in its courses, and all the depositions which rest on the Modified Drift have been laid down. River deltas have been formed in all their extent. The drainage of lakes has continued, and innumerable small lakes have been filled with beds of marl and peat, as previously explained, page 82 and Fig. 25. The beds of rivers have, in many instances, been sunken by erosion, though in others the shrinkage of the volume of water has caused them to rise by accumulation of sediment. Cavern erosions have been continued, though more frequently the diminution of water has arrested the work of cavern making. The formation of stalagmites and stalactites dates, generally, from the Glacial epoch, or even an older one. This is true of much of the work which we witness in progress. The erosion of gorges is generally a process of which we witness only the latest stages. The excavation of caverns must have been begun as soon as the land drainage found fissures in limestone formations through which to flow. The removal of soils and the exposure of underlying rocks has been in progress as long as land has existed. In some cases the work was completed and the land obliterated even before the modern epoch.

The drainage valleys and the deep-cut gorges with which we are familiar in the topography of the present epoch are largely results which have been in progress as long as the land surfaces have been exposed. Some of these works extend back, probably, into Palæozoic time; but some of the greatest, like the cañon of the Colorado, have been accomplished since late Tertiary time, as is proved by the age of the strata excavated. The valleys of the Hudson and Connecticut may date from the Palæozoic; but if so, their courses were both interrupted by the deposits and the orographic movements of the Triassic; to be reopened after the close of the Triassic. The actual submarine shore line of the coast of the United States, Fig. 358, is a feature in modern topography. It lies from 80 to 100 miles from the present shore, in about 500 feet of water. Off the harbor of New York, we find what appears to be an ancient channel of the Hudson River continued seaward when the land was some hundreds of feet higher. This may have been excavated as far back as Palæozoic time, when the Seaboard Land had its higher altitude, and may have

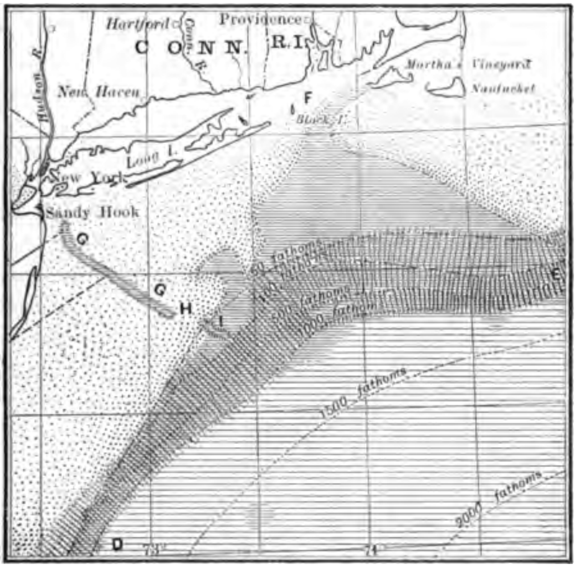


FIG. 358.—SUBMARINE CHANNEL OF THE HUDSON RIVER AND THE ANCIENT ATLANTIC SHORE. (After Lindenkohl.)

gone down with the eastern border of that land, when the Appalachian border reëmerged. The submerged Hudson channel, whenever formed, extends 80 miles to sea. At the distance of 10 miles its bottom is 48 feet below the general sea bottom. At 20 miles it is 90 feet below. At 50 miles it is 66 feet, and continues to diminish. At 80 miles is an ancient bar. The width of the channel is three-fourths of a mile to a mile. Beyond the bar is what appears like an ancient fiord, beginning about 85 miles from Sandy Hook, and extending 25 miles to the edge of the continental slope, with a width of about three miles. For half its length this ravine has a depth of over 2,000 feet. It is interrupted by a bar 1,600 feet high. The sides of this submarine river channel slope at an angle of one to three degrees; those of the fiord, 14 .

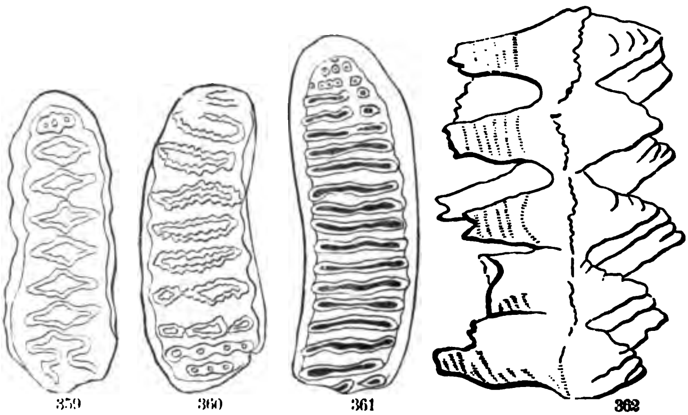
In the changes progressing under our observation we are furnished with clews to the explanation of the grander events of remote geological history. To a large extent these are but aggregates of slow operations continued through geologic æons. So far the method has been *uniformitarian*. In the elevation of the Uintas we witness, undoubtedly, as Powell has demonstrated, a grand result accomplished by slow movements, since the Green River has cut through the whole altitude of the range. But some *cataclysmic* events must have taken place, as convulsions like those of Kra-kat'oa, Ischia, and Andalusia, in our own day, would indicate. Much greater ones, but of the same order, must have occurred when the Wahsatch and Sierra Nevada were rent longitudinally, and the Basin Province sank a thousand feet along each of its borders. On the whole, however, the geological work in progress may be regarded as mirroring the nature of the methods of the operations which have formed the world. Assuming that the same modes of activity will continue in the remote future, we have ground for anticipating unrealized results as grand and transforming as any which have been realized in the history of the past.

(10) *Organic Remains of the Quaternary.* In the ordinary glacial Drift few relics of the organization of the epoch occur.

Yet pieces of white cedar are found at various depths down to 60 feet at least, in the modified Drift. In regions south of the glacial limits life continued to flourish — both on the land and in fresh waters. The great Quaternary Lakes Bonneville and Lahontan (whether Glacial or Champlain) on the eastern and western sides of the Great Basin, were stocked with fresh-water species of molluscs, of which the most abundant genera were *Limnæa*, *Pomatiopsis*, *Amnicola*, and *Succinea*. The Oregon Quaternary lakes were similarly inhabited. In the Champlain epoch the Gulf of St. Lawrence extended into the basin of Lake Champlain; and some molluscan remains have been left in the valley of the St. Lawrence, in the "Leda clays." The skeleton of a small white whale, *Beluga Vermontana*, has been discovered on the borders of Lake Champlain.

Of land mammals numerous species have been found in caverns and rock fissures, and in post-glacial surface deposits. The age of remains from caverns and fissures may be glacial or post-glacial; but remains in beds resting on the Drift must, of course, belong to the Champlain epoch, if of extinct species, or to the Recent epoch, probably, if of living species. A limestone fissure at Port Kennedy, Pa., has afforded Cope remains of 34 species of mammals, mostly extinct. Caves in Wythe county, Va.; at Galena, Ill.; and near Carlisle, Pa., have afforded many remains, some of which belong to extinct species.

In deposits more recent than the Glacial epoch have been found remains of a species of Elephant (*Elephas Americanus* — the same as *Elephas* or *Euelephas Jacksoni*) as large as the Quaternary Elephant of the Old World. The latter also (*Elephas primige'nius*) is found in the more northern latitudes of America (see Fig. 364). More frequent is the Mastodon — *Mastodon Americanus* (called also *M. giganteus* and *M. Ohioticus*) — found generally in peat bogs where, according to prevailing opinion, the creature became mired. But the carcass may also have been borne in by a flood while the bog was yet a lake. The Mastodon was abundant throughout the Northern United States. Three perfect skeletons have been exhumed in Orange county, New York; one near Cohoes Falls on the Mohawk, one in New Jersey, one in Indiana (destroyed in the great Chicago fire), and one from the banks of the Missouri. Skeletons imperfectly preserved have been found in very numerous localities, especially western. A nearly complete skeleton was exhumed near Tecumseh, Mich., and another in Cass county. Dr. Warren's Mastodon from near Newburgh has a height of 11 feet, with a length of 17 feet to the base of the tail. The tusks are 12 feet long, of which $2\frac{1}{2}$ feet are inserted in the sockets. The total height when living



FIGS. 359-362. — PLAN OF ENAMEL PLATES ON THE MOLAR CROWNS OF PROBOSCIDIANS. 359, Molar of African Elephant; 360, Indian Elephant; 361, Mammoth; 362, Molar of Mastodon, perspective view.

must have been 12 or 13 feet, and the length 24 or 25 feet. The Mastodon probably survived to the recent epoch. The Tecumseh Mastodon was buried in a small bog with only 18 inches of peat over it. In the same county Indian arrow heads are found seven feet beneath the surface of the peat. Mastodon remains are reported in Florida, south of the thirtieth parallel.

The most striking differences between the elephant and mastodon are found in the molar teeth; and these are illustrated in Figs. 359 to 362.

The post-glacial deposits of North America have afforded also the remains of a *Horse*, larger than the domestic species, a gigantic *Beaver* (*Castoroides Ohioensis*), of which an incisor is shown reduced in Fig. 363; pig-like and peccary-like animals; *Oxen*, *Bisons*, and *Tapirs;* also *Bears*, *Lions*, and *Raccoons*. Some Edentates, in our times almost peculiar to South America, extended their range northward to the Ohio River. They include several species of *Megal'onyx*, and one each of *Myl'odon* and *Megatherium*. From Florida are reported remains of *Rhinoceros*, *Stag*, *Camel*, *Tapir*, and *Hippopotamus*.

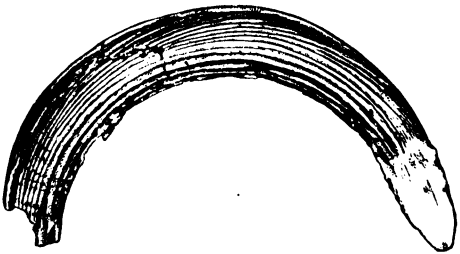


Fig. 363.—Incisor of the Extinct Gigantic Beaver (*Castoroides Ohioensis*). From Lapeer, Mich. × ½.

In South America Edendates were the predominant ordinal type, as they still are. The pampean formation of the southern part of the continent is a vast, level deposit, 20 to 100 feet deep, formed largely of materials borne eastward from the slopes of the Andes at a time when the Atlantic covered the country to the foot of the mountains. It stretches over the larger part of Patagonia and the Argentine Republic, embracing one and a half million square miles. This Quaternary formation is a literal cemetery of strange and mostly uncouth mammalian forms. The great *Megatherium Cuvieri* (Fig. 364) was larger than the Rhinoceros, and in some of its proportions exceeded the elephant. The femur was three times as thick as the elephant's. This animal was a huge ground sloth, with massive posterior extremities and post-like tail, which suggests its probable habit of standing erect to browse from the foliage of the forest. Other and associated Edendates were *Megal'onyx*, so named by President Jefferson; *Myl'odon*, larger than the American buffalo; *Scelidothe'rium*, an allied genus, and *Glyp'todon*, a huge armadillo, carapace-covered like a turtle.

In Europe, the oldest Quaternary relics are found in caverns.

They embrace the Cave Bear, Cave Hyæna, and Cave Lion, all somewhat larger than the nearest related modern species, but all regarded, at present, as identical with modern species, or derived from them. With these are found bones of the Mammoth (*Elephas primigenius*), Rhinoceros, Hippopotamus, Deer, Aurochs, or European Bison, and other species, and often implements of human production. The most celebrated bone caverns are those of Kirkdale, Kent's Hole, and Brixham, in Great Britain, and Gailenreuth, Périgord, and the Bordogne, on the continent.

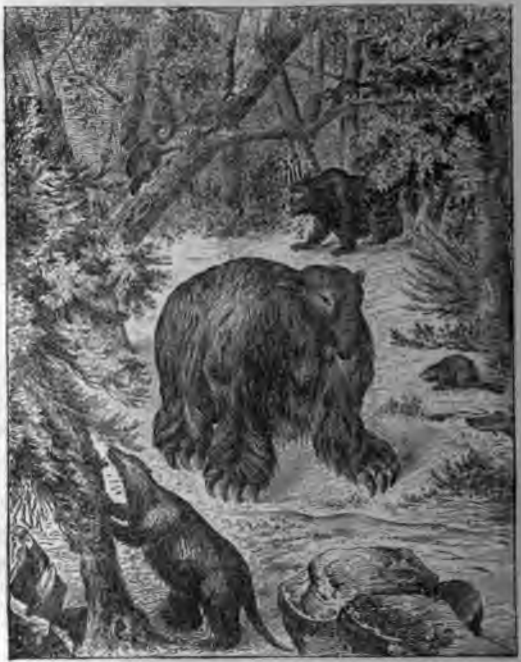


FIG. 364.—*Megathe'rium Cuvi'eri*, RESTORED. From the Pampas near Buenos Ayres.

The Mammoth extended into Siberia, and thence into Alaska. The tusks exist in such abundance as to constitute an article of export. The carcass of the Mammoth is sometimes found imbedded in permanent ice. In some cases the flesh is thus preserved, and supplies food for dogs, wolves, and foxes. In one celebrated instance, a carcass taken from ice near the mouth of the Lena furnished a skeleton which was mounted in the Museum at St. Petersburg. From this, and other bones discovered in Europe, Dr. Frass, of Stuttgardt, effected a restoration which is now in Ward's Natural History Establishment, at Rochester, N. Y. Of this, a representation is given in Fig. 365. It will be

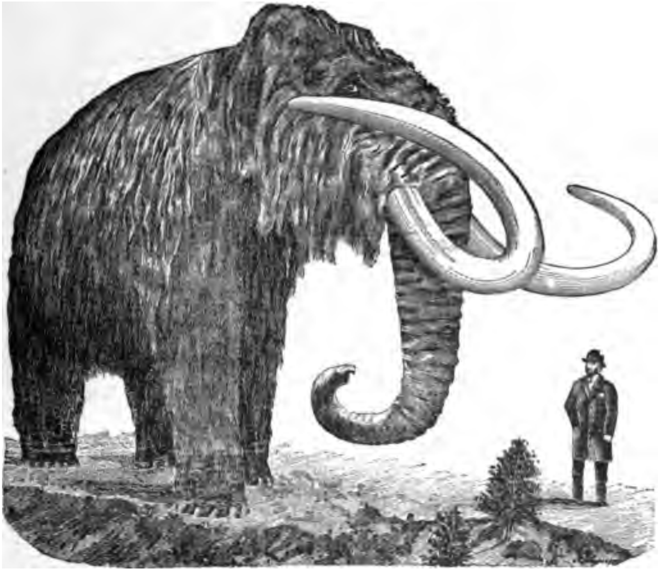


FIG. 365. — RESTORATION OF THE SIBERO-AMERICAN MAMMOTH (*Elephas primigenius*). (After Fraas and H. A. Ward.)

noticed that this elephant was warmly clad with hair of three kinds. The most abundant was reddish wool, an inch in length. Interspersed through this were reddish-brown hairs, four inches long, and sparser black bristles, twelve to sixteen inches long. It is reasonable to infer from the clothing that the mammoth inhabited a cold, or a cold-temperate climate in the epoch before the advent of continental glaciers. It appears, too, that the invasion of snow and permanent cold was sudden. The mammoth had no time for retreat. There was no returning springtime. The beast, once buried, remained frozen through a geologic period.

It has been believed that the mammoth had become extinct; but the mountains of Siam have yielded at least two young specimens of a hairy, perhaps dwarf, elephant, which seems clearly to be the descendant of the mammoth of the North. These elephants were imported into New York in 1884.

Human implements and human bones are found in European caverns, in interglacial deposits and in river drifts, associated with the relics of extinct mammals. It appears from the evidences that man, in a barbarous state, was a resident in Europe as early as the interglacial epoch. Some indications of his presence during the Pliocene, and even the Miocene, period, have been thought to exist; but the general opinion holds as insufficient the alleged evidence of his preglacial advent.

CHAPTER VI.

HISTORICAL GEOLOGY;

OR, WHAT HAS BEEN LEARNED ABOUT GEOLOGICAL PROGRESS.

§ 1. Presedimentary History.

ALL that can be said about the history of terrestrial matter during æons antecedent to the formation of enduring record-bearing rocks must be a deduction from (1) The ascertained laws of matter; (2) The conditions observed in other worlds; (3) The principles of world making disclosed in the rocky records of our planet. It is intended to offer only a few condensed statements.

It is generally believed that the matter of the earth and the whole solar system existed, at a very remote period, in a condition analogous to that of modern nebulæ. These probably consist of particles and masses accumulated through the action of gravitation, from wide realms of space. Through the processes of aggregation, heat and rotation are generated in the nebula. Our solar nebula was once in such a state. Through cooling and shrinkage, its rotation was accelerated, until a succession of rings was detached, each of which, in the course of time, assumed the form of a planet. Each planet was at first in the condition of discrete matter of high mobility, and in a state of rotation. Some of them, in turn, detached rings, which became satellites.

At some stage in the process of cooling, a portion of the matter of a planet, or the whole of it, existed in the condition of "fire-mist," or liquid particles of mineral matter, enveloped in other matter retaining the gaseous condition. Such was once our earth. At a later stage, however, the mineral particles descended toward the centre of gravity, and the planet became a molten globe. Enormous pressure at the centre may have reduced the central portion to a solid state; but this solidity was of a very different nature from that which resulted from cooling at the surface. From superficial cooling, a solid crust resulted, and this thickened continually.

In the course of time, but probably while the crust still retained an incandescent temperature, the vapor of water began to condense in the higher atmosphere. Before this, water could only exist in an invisible gas. Clouds now gathered around the world, and the first rains descended, amid scenes of terrific electrical disturbance. The falling rains hastened the thickening of the crust and the cooling of the surface; and in the course of a geologic age, water was permitted to accumulate in a film, which constituted a universal ocean. The descending rains had washed down the atmospheric acids, and the ocean was one of acid waters. These waters were hot. They rested on a crust which, from its mode of origin, was alkaline, and was ready to undergo chemical change as soon as an acid solution was brought in contact with it. In this ocean chemical action was intense. The results were soluble substances, like chlorides and sulphates, left in solution, and other substances, like silicates and calcium carbonate, precipitated. Thus precipitates accumulated over the ocean bottom; and to these were added such detritus as resulted from the mechanical action of the ocean in the shallowest situations. The thickened crust impeded the escape of internal heat, and this acted on the under side of the crust, re-fusing some portions, to restore the equilibrium thickness.

Thus the cooling, so long in progress, continued. But the crust did not cool in the same proportion as the internal mass; and wrinkles resulted. These assumed general meridional trends in consequence of ingrained predeterminations, caused by tidal actions during the incrustive stage, and by the progressive secular subsidence of the earth's equatorial protuberance, resulting from the slow diminution of rotational velocity. These wrinkles, whether submerged or emergent, furnished the waves new opportunities for detrital production. Thus the crust thickened at an increased rate in the more deeply submerged regions, and the removal of subjacent layers proceeded. What amount of the original crust may have been re-fused in this way can only be conjectured. As no portion of the original fire-formed crust has ever been discovered, we may infer that it was all returned to the molten interior. We may even conclude with probability that much of the super-crust, or stratified crust, was also re-fused; since the lowest strata yet explored fail to reveal the evidences of violent oceanic movements which must have taken place when the moon was much nearer the earth, and produced much greater tides, while, at the same time, the terrestrial day was shorter. When those sediments were deposited which have formed the oldest Laurentian rocks, the tidal and other physical forces appear to have been acting very much as in our times.

§ 2. Inductive History.

1. *The Eozoic Æon.* The visible rocks reveal a body of facts from which we may reason by inductive inference, as well as from the principles of nature. The history thus far deduced brings us down to the Eozoic Æon. To this Great System belongs the oldest rocks preserved for our study. There must have been sources of sediments then in existence, for these rocks are sedimentary in their nature, though the oldest cannot be pronounced characteristically fragmental. If there were any emergent lands during Eozoic time, we know not where they were. They have disappeared, consumed by the erosions which were preparing materials for the continental foundations of later ages. Perhaps the ocean was still universal, and the erosions were suffered by the shallower portions of the sea bottom. The rocks which resulted are before us, bearing, however, the marks of subsequent metamorphism, to an uncertain extent. We have passed these rocks in review. They overstrew the drift-covered surfaces. The deepest rocks are also very extensively the surface rocks.

With the progress of time, the conditions of rock formation changed. We have, in the same regions, gneisses, slates, conglomerates, and limestones, piled successively above each other. What was the nature of these changes we will not stop to inquire.

We know, to a certainty, that the Eozoic Æon was inconceivably long; and that the ocean reigned almost or quite universally.

Of life during the earlier ages, there was none. At length arrived a humble form, which planted itself upon the sea bottom, and opened the drama of organization. Of Eozoön, in its structure and affinities, we have learned in another connection. It was the reef builder of these twilight ages. But when Eozoön ceased to live and work there was a blank, so far as observation goes. In the Upper Laurentian and Huronian, no trace of organization has been discovered. We cannot admit, however, that life, once introduced, was permitted to become extinct, and thus create the necessity of a new beginning. We must conclude that the processes of metamorphism, which so transmuted many of the rocks, have completely obliterated all fossil remains. Probably the Huronian rocks once contained the records of Huronian life.

But of the physical vicissitudes of Eozoic time we can say more. The crustal wrinkling before mentioned was part of a method which was destined to be continued. Sediments of Laurentian age, hardened already by chemical, thermal, and mechanical actions, were mashed together by lateral pressure, crumpled where they could not be mashed, and uplifted in huge folds when the surplusage of circumference became too great to be disposed of by these methods. In other words, Laurentian folds of the crust rose toward or above the surface of the ocean.

Meantime, deposition proceeded. The new folds began to be worn down, and later deposits, known as Huronian, rested unconformably on them. There were probably other uplifts of the primal folds. If we reason correctly, it was yet Eozoic time when the Keweenian formations came into existence. In the region which has since been the basin of Lake Superior, igneous ejections occurred on a scale of great magnitude. Probably the region had become land through an uplift at the close of the Huronian. Over this area, great sheets of molten lava, welling through the broken crust, spread out for a distance of 300 miles from east to west, and 100 miles from north to south. The crust began to sink, as if a void had been produced beneath it. The sea returned, and covered the region. From the adjoining felsitic slopes large quantities of fragments were broken, and rolled as pebbles over the sunken lava sheet, till the surface became again dry land, or a mere shallow. Then the molten eruption recurred, and again a sinking was experienced. These outflows and subsidences, and interposed sedimentary sheets, were many times repeated.

The close of the Eozoic Æon now approached. Great submarine wrinkles, grouped in some cases in wide and massive systems, had been for ages rising to the surface of the ocean, and above its surface. The germinal areas of the North American continent had now emerged. The chief of these were three. (1) The *Laurentian* or *Great Northern Land.* This consisted of an irregularly arcuate ridge or broad mountain elevation encompassing the area now occupied by Hudson's Bay. Its longer limb stretched from the northern shore of Lake Huron, as it now exists, northwestward between Hudson's Bay and the MacKenzie River to the Arctic Ocean; while the shorter limb stretched from the same region northeastward to the coast of Labrador. (2) The *Seaboard Land.* This was a broad, crushed, and plicated swell or mass of wrinkles, stretching from Maine southwestward to Alabama, along the slope between the present Appalachians and the Atlantic Ocean. There is considerable reason to believe that in breadth it embraced the region which was destined in later ages to become the site of the Appalachian chain of mountains, though in the intervening time destined to undergo a long submergence. There is equal reason to conclude that this land extended eastward beyond the present Atlantic shore, perhaps to the brink of the slope into the deep sea. These conjectural dimensions are represented in the Æonic Map, Fig. 297. (3) The *Cordilleran Land.* This was the western germinal area. In width it stretched from the eastern base of the Rocky Mountains westward into eastern California, a distance of 750 miles along the parallel of 40°. It extended great, but unknown distances northward and southward. This land was a great mountain system, displaying lofty ranges made of crumpled strata; mechanical dislocations effected on a most gigantic scale, but withal a smoothness of surface contour, and an absence of deep cañons and worn gulches which seems to argue an absence of those methods of erosion which have determined the configuration of the modern surface. This massive belt of Eozoic Cordilleras determined the limits of the modern Cordilleras, and very much of the details of their fundamental structure.

2. *The Palæozoic Æon.* (1) *Movements of the Lands.* It was now a new morning in the world's history. The Cambrian Age was dawning. The corner stones of the continent had been deeply laid; yet over the site of North America an ocean expanse still brooded. The transition from Eozoic to Palæozoic time was marked by important orographic movements. While the Great Northern Land stood unmoved, the Seaboard and Cordilleran lands underwent great subsidence. The western part of the former and the eastern part of the latter went down beneath sea level; and Palæozoic sediments began to be spread out over them. Of the Seaboard Land, the Appalachian site became submerged. Of the Cordilleran Land, all subsided from the region of the Great Plains to eastern California. Only the granitic mountain summits stood emergent. The broad continent had become an archipelago. Highest stood the Colorado, Medicine Bow, and Park ranges, on the eastern border of the sunken land. The continental mass remaining was on the western border. It was destined to be wasted in yielding the materials to be spread over the ocean bottom, for the upbuilding of the Palæozoic formations. While this sunken Cordilleran surface was receiving its load, it continued to sink. But as the coarsest and most copious deposition was near the wasting Nevada Land which yielded the materials, the subsidence was greatest on the west. By the end of the Palæozoic Æon the thickness of the Palæozoic sediments was a thousand feet around the bases of the Rocky Mountain ranges; 32,000 feet in the Wahsatch region, and 40,000 feet at the extreme western Palæozoic limit in longitude

117° 30′. So deeply was the grand Cordilleran topography of the close of Eozoic time buried from observation.

Similar was the experience of the ancient Seaboard Land. The Appalachian border, which sank at the end of Eozoic time, continued to sink during the whole of Palæozoic time. Sediments accumulated upon it to the depth of 45,000 feet. Westward toward the modern Mississippi Valley, they diminish to 6,000 and even to 3,500 feet.

Quite the reverse was the movement of the Laurentian Land. Its tendency was upward. Some additional elevation was apparent at the end of each succeeding Age. When the close of Palæozoic time was approaching, its area had been widened so as to embrace most of New England, New York, the Upper Peninsula of Michigan, Wisconsin, and most of Minnesota. Similar enlargement was experienced along its other borders.

(2) *Progress of Animal Organization.* While these great physical transformations were in progress, parallel transformations and parallel progress were going forward in the organic life of the planet. Eozoön had long since ceased to be a tenant of the ocean; but its great works were lying imperishable beneath the accumulating masses of the forming continent. As soon as the tumult of the closing action of Eozoic time had subsided, the Palæozoic ocean was thronged with creatures of grades comparatively high — Trilobites, Chambered Molluscs, Gasteropods, and Brachiopods. Coral animals, Crinoids, Lamellibranchs followed quickly, geologically speaking. In those distant ages were all the experiences which characterize life of our own times — hunger, fear, pursuit and retreat, slaughters and the pangs of dying. The very attitudes in which the dead were buried reveal the shrinking which sentient organization experiences when the pains of dying approach. But through all the wide ocean no place was found for creatures conformed to the highest, or vertebrate, type of structure. It was the Reign of Invertebrates.

As the land extended its borders, and the elements became suited to the requirements of higher types of life, there were, first, premonitions of the advent of vertebrates, and then the on-coming of the powerful and cruel dynasty of armored Fishes. They ruled during the later Silurian, the Devonian, and the Carboniferous ages. Until the last period of the Carboniferous, vertebrate life was exclusively aquatic, and, so far as we know, almost exclusively marine. When the atmosphere had become respirable, some humble Amphibian forms might have been seen skulking under the protection of the flowerless herbage which had sprung up. But plated, bony-scaled, and shark-like fishes remained the dominant vertebrates.

(3) *The Coal Period.* The last period of the Palæozoic Æon was marked by its exuberance of vegetal life. Marine plants had existed in the early Laurentian. Their record stands in the beds of graphite which were then formed, and the deposits of magnetite and hæmatite which are believed to have been accumulated through organic agency. Scattered land plants are thought to have flourished along the Silurian and even the Cambrian shores, since some obscure driftwood has been taken from beds of the Cincinnati Group. During the Devonian ferns and lepidodendroids left their relics in considerable abundance; but during the last period of the Palæozoic the situation became peculiarly suited, in the eastern portions of North America, for the development of an extraordinary volume of vegetation.

The sinking of the Appalachian geosynclinal had been such that the Palæozoic sediments accumulated, together, perhaps, with a little subsequent elevation, brought the sea bottom up to the sea level, or a little above. In regions farther west — in Ohio, Michigan, Kentucky, Indiana, Illinois, Iowa, Missouri, and eastern Kansas — the general tenor of upheaval begun at the end of Eozoic time, had brought the sea bottom up to nearly the same level as it reached in the Appalachian region. Over the broad marsh land, which thus stretched half across the continent, conditions uncommonly favorable for vegetable growth existed. The whole expanse, therefore, became clothed with a general type of vegetation in correspondence with the primitive conditions of the world — mostly ferns, calamites, sigillarians, and lepidodendroids. The growth and prostration of this vegetation through a succession of generations resulted in a bed of vegetable material somewhat peat-like in its nature, and, like peat, preserved from decay by saturation in water and exclusion of air. Then followed a subsidence of the whole of the coal-making area. The ocean returned, and sheets of fragmental deposits buried the vast peat bog, to undergo those transformations which should eventually bring it into the condition of bituminous coal. Another uplift succeeded, and new growths covered the new land. Another bed of vegetable matter accumulated, and another submergence resulted in its burial beneath strata of sand and mud. Thus emergences and submergences succeeded each other during the entire coal-making period. It is not supposed, however, that all these movements were synchronous over the entire coal-making area. Undoubtedly, some portions underwent, at times, a degree of submergence, while others remained above sea level. The emergences, also, must have been experienced sometimes earlier in one part of the area than in others. The nonsynchronism of these movements resulted in some discontinuity of the beds of coal, shale, and sandstone thus forming. Hence the succession of strata in Illinois is not identical with the succession in Ohio and Pennsylvania.

While these oscillations of level were in progress in the eastern part of the continent, the Cordilleran region, as a whole, remained permanently beneath the ocean. The ancient island mountains still stood emergent, and the Nevadan land continued to crumble, in furnishing the sediments which formed the last layers of the Palæozoic mass.

(4) *Close of the Palæozoic.* Great geologic events were now at hand. The broad coal-making region so long oscillating upward and downward, as if under the stress of an enormous lateral pressure from which it was seeking relief, at length yielded to the resistless strain. Huge parallel folds of the crust rose along the Appalachian region. A mountain chain came into existence where sea bottom had been during all the Palæozoic time, save the period of bog lands while the coal beds had formed. The mountains rose to altitudes of twelve to fifteen thousand feet.

Before human eyes rested on them they had lost by erosion half their original height. The disturbance was felt as far as eastern Kansas. All the intervening region became upland.

There is reason to conclude that the remnant of the Seaboard Land went down as the Appalachian belt came up. Thus an unknown amount of that land became subsequently concealed by sediments of later date. The Triassic sandstones of Connecticut, New Jersey, and seaboard districts farther south prove that immediately after the Appalachian disturbance the border was considerably more depressed than at present, and the Appalachian movement may probably have been the counterpart of this depression.

From eastern Kansas westward the great interior ocean remained undisturbed, save here and there a moderate upward movement revealed in the broader emergence of the protruding granite masses. But in the Wahsatch region, and westward, enormous alterations of level took place. The long worn Nevadan Land now sunk beneath sea level, while, reciprocally, the sea bottom immediately eastward, as far as the Wahsatch, and including that range, rose to a continental emergence. This was now the western continent, lying between the eastern foot of the Wahsatch and western Nevada, in longitude 117° 30′—the region now known as the "Basin Province." Between the new Basin Continent and the old Nevadan continent which went down there was a complete change of conditions. The continental see-saw on the west was the counterpart of the continental see-saw on the Atlantic border. The mass in each case which went down was on the side of the ocean; the mass which came up was next the interior. The continental masses were now settled for another age of repose.

3. *The Mesozoic Æon.* (1) *Continental History.* East of the Great Plains the land was now extended nearly to its destined dimensions (see Fig. 353). A belt along the Atlantic was still submerged, and also a broad belt on the Gulf border. The latter sent a triangular arm of the sea northward to Illinois, and widened westward into an ocean which stretched over the central

part of the continent as far, probably, as the Arctic Ocean. Its eastern border was in Minnesota, near the 94th meridian, and in Kansas, near the 96th. Its western border was at the foot of the Wahsatch, near the 111th meridian. It stretched continuously over the Great Plains, was broken into an archipelago in the Rocky Mountain belt, and was diversified with a few island emergences, especially northward, across the intervening distance to the Basin continent. North and south this Intercontinental Sea reached to the Gulf and the Arctic Ocean. Over this area Mesozoic sediments were spread. They rested conformably — at least in the 40th parallel region — on the latest Palæozoic. The source of the materials being on the west, the thickest accumulations were in that direction. Their general thickness at the close of the Jurassic Age was about 4,000 feet. West of the Basin continent was another ocean. All the Nevadan and east Californian part of it had resulted from the post-Palæozoic subsidence of land which had stood from the close of Eozoic time. The submerged surface, therefore, was deeply eroded. Over this the Mesozoic sediments were now deposited unconformably. They accumulated to a depth of twenty thousand feet. The belt along the western border of the Basin continent was destined to form the Sierra Nevada mass. Meantime the Appalachians were wasting, and the débris were strewn along the contemporaneous Atlantic and Gulf border, from Sandy Hook to Georgia, and from Georgia to Texas.

The close of the Jurassic Age was now at hand. It was signalized, especially, by the rise of the vast crumpled folds of the Sierra Nevada. This added 200 miles to the westward extension of the Basin continent, which thus became the Basin-Nevada continent. It stretched southward at least to the 36th parallel, and probably to the 32d. Northward it extended into Washington Territory, and perhaps to the Olympic Mountains. East of the Wahsatch, however, this great disturbance was not felt, save that its rock fragments and finer *débris* were sent eastward over the ocean's floor as far as Kansas. These coarse materials formed the basal or Dakota member of the Cretaceous System. But it was laid down conformably on the Jurassic.

Along the Atlantic border the Cretaceous Age was marked by a moderate depression. The ocean encroached farther inland than during the Jurassic. The Cretaceous sediments, accordingly, covered and concealed nearly all the Triassic and Jurassic. The same statement applies, also, to the Gulf border.

The close of the Cretaceous was an important era in American geological history. To this epoch, the sedimentary sheets of the central region east of the Wahsatch had been laid down in conformable superposition from the beginning of the Palæozoic. Now, however, came the turn of the region at present known as the "Plateau Province." Upward and undulatory movements were experienced. Now rose the broad, flat, east and west anticlinal range, known as the Uinta Mountains. Not, however, by a sudden movement, for the rise was prolonged through the whole duration of the resulting land surface, and proceeded slowly enough to permit the drainage streams to saw chasms through the entire height of the mountain. Eastward of the Uinta, the whole continental mass was raised; and this brought with it the Rocky Mountain ranges to a higher altitude. The broad, shallow basin of the Colorado now had its limits marked out. On the Pacific Coast, this disturbance was felt only in the defining of the position of the Coast Ranges. On the Atlantic and Gulf, the continent was upraised; and a belt ranging from fifty to a hundred miles was added to the land.

These changes, however, were not accomplished with abruptness. The Cordilleran sea bottom was slowly rising during the whole Cretaceous Age, reaching the vicinity of sea level at an earlier epoch on the Wahsatch border than in the region of the Rocky Mountains and Kansas. Farther south, however, in Texas, the Cretaceous ocean remained a deep sea till the close of the Age.

The great feature of the Cretaceous and post-Cretaceous movements was the reëmergence of that part of the ancient Cordilleran area which is now called the Plateau Province, though, indeed, extensive inland lakes continued through the next æon. The two limbs of the American continent were now joined together. From middle California to Boston Bay was a continuous land connection. Only a narrow border remained to be added around the Atlantic, Pacific, and Gulf coasts, and North America would be complete.

(2) *Progress of Mesozoic Life.* Vegetable organization reached, in the early Mesozoic, the grade of Cycads and Conifers. Tree Ferns were still abundant. In the later Mesozoic, angiosperms and palms were common. The marsh borders of the emerging lands of the Dakota period have preserved a great abundance of the leaves of plants belonging to modern and closely related genera. Lesquereux, in a recent publication, enumerates from the Dakota Cretaceous 91 species of flowering plants, belonging to 29 living genera. These include 4 species of Sequoia, 7 of Oak, 5 of Willow, 5 of Poplar, 5 of Plane Tree, 7 of Fig, 4 of Magnolia, 8 of Tulip Tree, 9 of Sassafras, 8 of Sarsaparilla. Evidently the forest-covered land presented, in the early Cretaceous, a decidedly modern aspect. American Cretaceous vegetation was, in fact, more advanced than that of Europe. In the Laramie, or closing period, it had, according to Lesquereux, an Eocene, or even a Miocene, aspect. That is, the nearest European analogues of Laramie species occur in the Eocene rather than in the Cretaceous. At the same time, the reptilian and molluscan species of the Laramie are indisputably Cretaceous; and these are best suited to determine the age of a formation. Sir W. Dawson, in a very recent note (1885), records the occurrence of *Brasenice antiqua* in beds of the Belly River series, in the Canadian Northwest. This species is scarcely distinguishable from the modern *Brasenice* (*Hydropeltis*) *purpurea*, though it occurs in strata older than those affording remains of *Diclonius*, a Cretaceous Dinosaur. The horizon is probably Laramie.

Among Polyp corals, the ancient type of Tetracoralla, having the parts in multiples of four, were mostly extinct, and modern Hexacoralla had taken their place. The type of Crinoids, which had culminated in the earlier Carboniferous, was now declining, and the higher Starfishes and Echinoids were succeeding. The old spire-bearing Brachiopods, as also the Orthids and Strophomenoids, and other types, had dropped out of existence; and Terebratuloids were now in the ascendent. The waters swarmed, however, with Lamellibranchs and Gasteropods. The higher molluscs were richly represented by Ammonites and Belemnites. But the former showed, toward the close of the Cretaceous, a marked decline. Ganoid and Selachian fishes continued in abundance; but the former early dispensed with the vertebrated tail. This is an embryonic character, and accordingly belonged to the early stages of type development. The reptiles were the great feature of the life of the Æon. Their modes of life and diversification of type have been elsewhere described. Their graduation into the type of birds presents facts full of curious and philosophic interest. Perhaps the most significant event was the advent of Mammals; since this brought organization up to the class-grade of man, and constituted a final renewal of the promise of man's ultimate advent. The first mammals dwelt on the Triassic land, and were feeble and inconspicuous. In the Jurassic Age, they were still feeble, but somewhat more numerous. In the Cretaceous they seem to have gained nothing in bulk, power, or importance. Evidently, the appropriate age for the unfolding of the Mammalian type had not yet arrived.

4. *The Cænozoic Æon.* (1) *The Tertiary Age.* It will be remembered that Mesozoic time was concluded by an uplift of the whole Cordilleran region, and the extinction of the great Plateau or mediterranean sea. But in the basin of the Colorado River, a great depression remained without complete drainage to the sea. There rested, during the Eocene, a great Eocene Lake, extending from the upper waters of the Yellowstone to New Mexico. This, at first salt, became brackish, and, at length, a lake of fresh water. The sediments accumulated in it during the the first epoch constitute the Wahsatch formation (=Vermillion Creek Group, King; = Bitter Creek Group, Powell). In the progress of time occurred three successive orographic disturb-

ances. The first, during the progress of the Wahsatch, contracted the great lake on the north and south. It stretched now from the valley of the Green River north and south of the Uinta Mountains, and perhaps, also, to the west of the Wahsatch Range, in Utah and Nevada. In it were deposited the sediments forming the Green River division of the Wahsatch formation (= Elk Group, King).

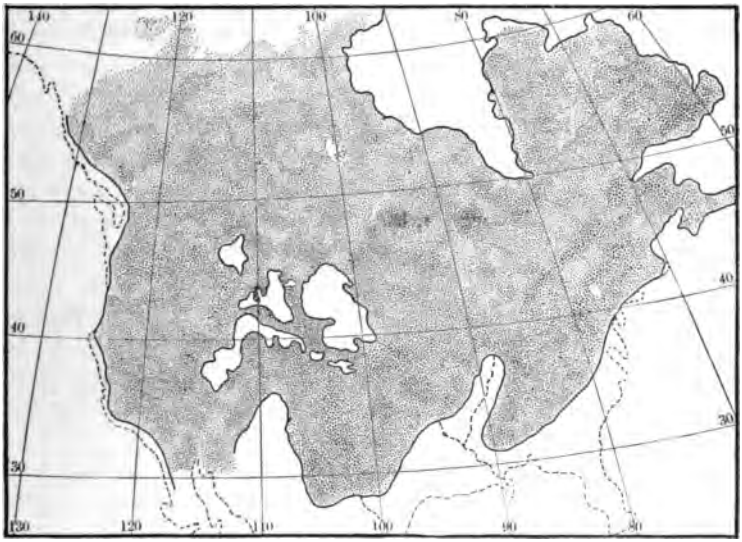


FIG. 366.—NORTH AMERICA, NEAR THE BEGINNING OF CÆNOZOIC TIME.

The second disturbance terminated the Wahsatch epoch. The great Eocene Lake was now further contracted. It consisted, during this epoch, of two or more divisions. One of these rested in the Green River basin north of the Uinta Mountains; another, the Washakie basin, lay east of the Green River, and a third was in western Colorado. The deposits collected formed the Bridger Group.

The third disturbance restricted the Eocene Lake to the region east and south of the Uinta Mountains, in the valley of the Green and White rivers. In it was deposited the uppermost of the Eocene formations—the Uinta (= Brown's Creek Group, Powell). During these events the province of the Great Plains appears to have been partly dry land.

The next orographic movement terminated the Eocene. The Great Plains were now depressed, and a lake stretched from the Missouri River to eastern Wyoming, Colorado, and the Wind River Valley, and from northern Kansas far into British America. A long, narrow depression took place, also, in the far West, along the eastern base of the Cascade Range and Sierra Nevada. It stretched from Washington Territory through Oregon, Nevada, and California. The deposits in the western lake were chiefly the tuffs and rearranged ejecta of volcanic eruption, and attained a thickness of 4,000 feet. The deposits in the eastern lake were the simple detritus from surrounding lands, and attained a thickness of 150 feet in Nebraska, 300 feet in Colorado, and 2,000 feet in the Uinta Mountains. The western is the Truckee formation (= John Day Group, King); the eastern, the White River formation; but some uncertainty remains as to their precise synchronism. Along the Pacific slope, deposits accumulated to the depth of four or five thousand feet in California and Oregon, which, with the closing disturbance, were upraised in the Coast Ranges.

This disturbance changed again the bounds of the interior lakes, and inaugurated the Pliocene epoch. The whole interior seems to have experienced a general depression, which interrupted the drainage to the sea. The western Miocene beds were thrown into folds. The resulting lake was divided in two by the archipelago of the Rocky Mountains. We find the deposits of the Pliocene or Loup River beds at many points between the Sierra Nevada and the eastern limit of the Great Plains, and from Oregon to New Mexico. They reach into Kansas and stretch northward, occupying the valleys of the Rocky Mountains. They embrace the Niobrara Group, King and Marsh + Humboldt Group, King + North Park Group, Hague and Hayden. The Pliocene beds of the Great Plains rest conformably on the Miocene, or, in some regions, on the Cretaceous, and attain a thickness of 2,000 feet. Those of the Basin and Plateau provinces rest unconformably on the Miocene, and are not over 1,000 feet thick. After the shrinkage of the Loup River lakes, deposition continued, forming the so called Equus Beds or Upper Pliocene (sometimes also regarded as post-Pliocene) occurring in Oregon, California, and Nevada; and in the eastern United States, in cavern and clay deposits along the Delaware and Potomac rivers.

The movement which inaugurated the Pliocene appears to have resulted in an elevation of the Atlantic seaboard north of South Carolina. During the Pliocene, probably the submerged shore land off the present coast marked the border of the land. During the Pliocene, also, the submerged Hudson gorge was principally elevated (Fig. 358). Throughout the Tertiary the Atlantic and Gulf coasts experienced a slow and mostly progressive upheaval. But the most considerable emergence on the Gulf and South Atlantic was at the end of the Eocene, and along the North Atlantic, after the Miocene.

The continental oscillations sketched in the foregoing paragraphs are graphically represented in the accompanying æonic sections, Fig. 367. The sections are mere diagrams, representing uplifts and subsidences; but they will greatly aid the memory and imagination in retaining a vivid conception of the locality and order of succession of each of those great orographic movements which have made American geology what it is, and have shaped the face of the continent in those forms destined to characterize it through the age of human occupation.

(2) *The Glacial Epoch.* During the later Tertiary moderate elevations occurred in various regions, completing the drainage of the land, and establishing a tenor of events destined to continue to such extent as to determine the advent of another epoch. The continuance of the elevation became general over the northern part of the continent, and more especially the northeastern. The climate, therefore, which had been milder than our present climate, experienced an increase of winter severity, and a prolongation of the snowy season. The higher elevation of the land increased the corrasive action of the streams and deepened their channels. It also produced an extension of the land along the

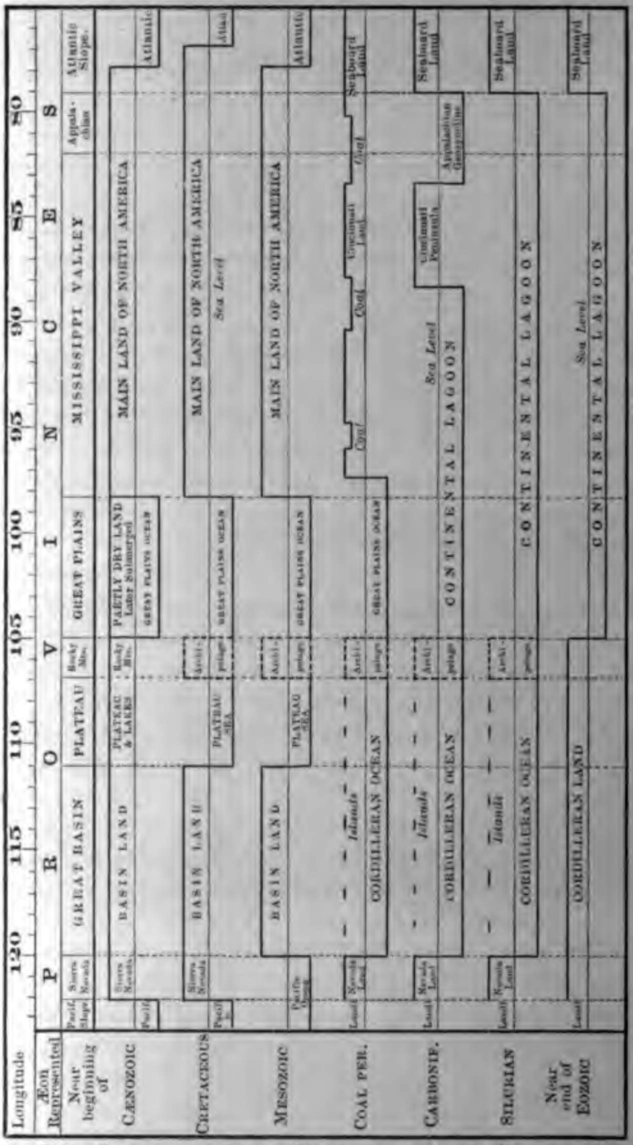


FIG. 367.—ÆONIC SECTIONS ACROSS THE CONTINENT ALONG THE FORTIETH PARALLEL. [East of the 83d meridian the Sections follow the 38th Parallel.] Compare with Æonic Maps, Figs. 297, 304, 312, 349, 353, 354, and 356.

sea border. It is probable that the border of the steep basin slope of the Atlantic, before mentioned, marks the position of the ancient shore in post-Pliocene, if not in Pliocene, time. This, however, could not have formed the continental border along the South Atlantic during Pliocene time, since in South Carolina, Pliocene deposits prove Pliocene submergence. In early post-Pliocene time, Long Island was 150 miles broad, and the western part of Long Island Sound was the lower valley of the Connecticut River. The Hudson River still pursued its course between high banks, 135 miles beyond New York. This supposes the post-Pliocene elevation of the land to have been equal to the highest attained.

With progressive northern elevation, the rigor of the climate increased. The northern zone of perpetual snow widened to temperate latitudes. Under the influence of the summer sun, the broad snow mass, though not dissipated, was reduced to the condition of glacier ice. The snows had fallen over the landscape, and bedded themselves about the trees of the forest. They had gathered themselves about all the rocky saliences, and filled the rugged gorges worn by the long corrading streams. When, therefore, the pervading glacier moved, as all glaciers must move, the forests were prostrated, and the rocky crags were wrenched from their fastenings. The angular fragments were frozen in the glacier's bottom, and like diamonds in their setting, they scored the underlying surface. That surface was covered with sands and clays and rock fragments, the result of the rock disintegration of hundreds of thousands of years. This incoherent material was moved and mixed by the glacier. With it were mingled the shattered remnants of the forest. By it the old gorges and gullies and river valleys were filled. These *débris* of former ages were swept clean from the solid surface of the rocks; and the moving glacier mass scoured and scored the solid rocks. It slid over moderate elevations, and crossed many of the valleys which intercepted its course. Eastward, it travelled over Long Island, and out to the ancient shore. In Ohio it reached the Ohio River. Farther west, its limit was reached in latitudes considerably higher. It will be understood that the southern glacier limit was coincident with the southern limit of the Drift, as shown on the map, Fig. 356.

The course of the continental glacier was not independent of the larger topographic features of the land. It tended to move downward from all elevations. The courses of the great valleys determined deflections sometimes for a hundred miles or more. It followed *up* the valley of the St. Lawrence. It continued along the axis of Lake Erie, and up the valley of the Maumee; but it will be remembered that the slopes were different, sometimes reversed by the northern elevation of the epoch. The glacier filled the valley of the Connecticut with a broad ice river. It flowed down the valleys of the Mohawk and the Hudson. Pursuing its way along the channel now submerged, it excavated the great fiord which lies now over a hundred miles at sea, and sunken in 500 feet of water. It accumulated to a depth of, perhaps, 5,000 feet. At this depth the heat from the earth's interior would be sufficient to melt the glacier beneath as rapidly as any probable growth above. The sub-glacial melting created copious sub-glacial streams, which transported detrital material, and contributed much to the observed arrangements of the Drift.

In regions beyond the limits of the continental glacier, local glaciers gathered on mountain summits and slopes, and coursed down the mountain valleys, as modern glaciers move in Alpine valleys. Such mountain glaciers clothed the higher slopes of the Appalachians, the Rocky Mountains, the Sierra Nevada, and most other ranges farther north. The remnants of some of these local glaciers survive to our times. (See especially the Memoir of I. C. Russell.) Even the modern Alpine glaciers are but vestiges of a wide general glaciation. Under such a sheet of ice lay, for probably thousands of years, the fair continent which in geologically recent times had been clothed with a forest which gave it an aspect exceedingly like that of a modern landscape. The desolate surface of glacier-clad Greenland remains a vivid picture of northeastern North America only a few thousand years ago.

It is not necessary to suppose the climate was characterized by excessive cold. Moisture and precipitation are necessary. Where these are abundant, the snow accumulation may outlast a summer of high temperature. The glaciers of the Alps descend to the borders of the fields where crops of grass and potatoes grow. The snow in Tuckerman's ravine, in the White Mountains, lasts till August, *because it is abundant.* In the same climate the general accumulation of snow might be sufficient to last till snow falls again. With the surface widely covered, the temperature could not rise much above 32° Fahr., and less snow would then suffice to withstand the whole summer heat. The continental glacier existed in the eastern United States, where precipitation is now greatest. It was wanting over the Great Plains and the Northwest, where precipitation is still scanty.

(3) *The Champlain Epoch.* The epoch of elevation and cold was followed by one of subsidence and warmth. From its extreme limit the continental glacier began to retreat. There must have been left originally a terminal moraine of great magnitude. The melting of the ice across half the breadth of the continent resulted in floods, which swept southward, carrying the incoherent products of glaciation, and depositing them in the state of confused stratification which we see in the Modified Drift. To what extent the retreat continued we have no means of learning. It appears, however, that some portions of the uncovered surface, as over central Illinois, had time to develop a considerable amount of vegetation and form a soil.

Then followed a return of cold, and the glacier again advanced. It does not appear that the second advance was equal to the first. On the final retreat the great terminal moraine was left, which has been traced so continuously across the country, and mapped in Fig. 356. The return of another geological springtime gave birth to renewed floods, which continued the work begun at the time of the previous thaw. These new floods swept over the old moraine, and probably scattered and levelled to a large extent the accumulation of materials. This may explain the less conspicuous character of this moraine, though formed through the action of the severest cold and the most extended glacier. The glacial flood sought, of course, the valleys of the great streams for its main outlet to the sea, and thus bore far southward large quantities of driftwood, and even ice rafts with loads of sand and bowlders. But the flood swept also over the general surface of the land; and thus the states not reached by the action of the ice were reached and benefited by the action of the flood which sprang from the ice.

It is to be remarked that the aggregate action of the Glacial and Champlain epochs was directly ameliorative, and may be regarded as a preparation for the needs of the new fauna and flora which were destined to appear. As a general principle, it may be asserted that each renewed terrestrial surface in the whole history of life has been exhausted in supplying the needs of the population introduced to occupy it. The present terrestrial surface is visibly deteriorating. The pre-glacial surface had been wasted and scored by the erosions of the Æon which supplied the demands of Pliocene populations. By glacier action the old scars were removed – the gaping gorges were filled; the rock materials disintegrated through ages were stirred to the bed rock, and distributed in a continuous sheet; new materials originated from glacial wear; and when the floods came, a beneficent assortment left the finer products at the surface, and extended the reparative action over several degrees of latitude southward. The final result was a land surface specially suited to the needs of an industrial and civilized race of men.

The course of things thus in progress continued until the northward subsidence carried the land far below its pre-glacial level, and even below its present level. The consequence was an encroachment of the sea on the land. The records of beach action still remain at various altitudes above present sea level, showing the greatest Champlain depression northward. It thus appears that southern New England sank 10 to 25 feet below its present level; Sancati Head on Nantucket, 85 feet; parts of the coast region of Maine, 217 feet; the borders of Lake Champlain, 350 to 400 feet; the region of Montreal, nearly 500 feet; that of the Bay of Fundy, 350 to 400 feet; the Labrador coast, 400 to 500 feet; parts of the Arctic regions, over 1,000 feet. On Bennett Island De Long found beach deposits at the height of 100 feet. Marine shells were found 1,000 feet above the Arctic level; bnt it does not appear that they were not Pliocene or Miocene. Whether this subsidence was felt by the interior of the continent it is impossible to state. The Pliocene of the Great Plains remains from 4,000 to 7,000 feet above sea level; and the fact renders questionable any higher Quaternary elevation or any Champlain subsidence.

The subsidence of the land caused a reversal of a portion of the drainage of the Northern States. While the North was elevated, Winnipeg Lake, then greatly increased in dimensions, was drained into the Missouri. It has even been suggested that a large stream flowed southward through the present valley of the Minnesota. The great lakes also found various outlets toward the south. With subsidence of the land some of these courses became obstructed, and others even reversed.

(4) *Effects of Glacier Pressure.* In thus delineating the events of the Quaternary Age, I have followed the accepted teaching. But I think it may be useful to suggest some consequences of glacier pressure over the northern and eastern parts of the continent, which may necessitate some modifications of accepted views. If, as is now commonly held, the accumulation of marine sediments may suffice to depress the earth's crust under the sea, assuredly the accumulation of 5,000 feet of ice upon the land, over half the area of a continent, would cause a depression of the terrestrial crust — such as glaciated Greenland, for instance, is actually undergoing. Croll, assuming the crust to remain rigid under such a pressure, has discussed the necessary shifting of the earth's centre of gravity, and consequent flooding of northern regions. But the same flooding would ensue without a shifting of the centre of gravity, if the crust were depressed. If then the northern subsidence and submergence noted were coincident with glaciation, instead of subsequent, the phenomena resulting would be precisely such as we observe. The glacier

would not persist along shores buried by the sea. The same sea bottom would be there as if the glacier had disappeared from all the land. So the submergence seems to have been coeval with glaciation rather than subsequent.

Again, a sub-glacial depression over the north and east of the continent must have reacted beneath the crust in other regions — and especially in regions bordered by the depression, and most especially if bordered on the east as well as the north. The last was the situation of temperate North America west of the Rocky Mountains. Now the evidence is that the Plateau and Basin Provinces have suffered from powerful vertical actions. That enormous outflows of lava have occurred is another striking fact. These occurrences have been generally synchronized with the close of the Pliocene Epoch; but here are grounds for assuming them to have been coincident with the great submergence at the east.

(5) *The Recent Epoch.* The rise of the land from its deep submergence to its present general altitude marks the beginning of the Recent Epoch. As the land did not return to its former elevation, a wide belt along the Atlantic shore northward remains submerged. In the interior the descent of the streams is less than formerly. Hence their rate of flow is less, and their ancient channels remain partly filled with Drift deposits. Most of the larger streams now flow many feet above their ancient beds.

When the present level of the land was assumed, the water of Lakes Erie, Huron, and Michigan stood many feet above the present level. This was probably due, as has been explained, to an obstruction then existing at the escarpment over which, near Lewiston, the drainage of these lakes had to pass. During this period of high water the so called "Erie clays" were deposited which we now see along the borders of these lakes. The simultaneous high floods of the rivers, which left their terraces at various high elevations, were due, perhaps, to the prolonged melting of the ice, and partly, perhaps, to a continuance, at moderated temperatures, of that copious precipitation which at snowy temperatures had been the essential condition of glacier formation.

Thus there may have been a *pluvial epoch*, beginning during the progress of the Champlain moderation of climate, and extending down into recent times. The diminution of precipitation which then followed appears to be continuing into the present.

The subsidence of the floods left innumerable small lakes scattered over surfaces having but little slope. The peculiar kettle-like configuration of parts of the surface, especially along the morainic belts, favored the retention of small bodies of water. With the lapse of time, drainage outlets have been worn for some of these, and others have been completely filled with deposits of marl and peat.

In the present epoch, the land has the appearance of stability, except as occasionally affected by momentary earthquake movements. In truth, however, many shores are undergoing slow elevation or depression. These are movements which, in centuries, or at least in geological periods, may amount to changes of level as great as any which geological research has brought to light. The coast of New Jersey, for instance, is represented by Professor Cook as subsiding at the rate of two feet in a hundred years. At Uddevalla, in Sweden, the coast is rising above the Baltic level at the rate of four feet in a century; and north of that, the rise is more rapid. Along six hundred miles of the coast of Greenland, a slow subsidence is taking place. Numerous facts of this kind are known.

When the rivers were at flood on the continent of Europe, man was there. He was present, apparently, during an earlier, interglacial epoch. In America, he found a home during the same epoch, as far north as New Jersey, and, in unglaciated California, he left his bones buried in the gravels which underlie great lava sheets poured out in early Quaternary, or late Pliocene times. That man existed in remote preglacial times is not improbable; but he was represented by an inferior race, and lived in some congenial climate. The men who pressed upon the borders of the retreating ice were hardy adventurers, who had already come into the possession of the arts needed to secure comforts under trying climatic conditions.

But, in any view of the epoch of human origin, man stands as the crowning and consummated event in a series of intelligible preparations and promises which extend back through vast intervals of time to *Eozoön* and the primeval ocean.

§ 3. Ulterior History.

We need not remain in complete ignorance of that part of the world's appointed history which is yet future. It is scarcely true that we cannot be certain of any event which yet lacks realization. But, if it were true, there are impending events so nearly certain that, like to-morrow's sunrise, their failure can be determined by nothing less than a suspension of the order of nature as known to us; and knowledge, within the limitations of the recognized order of nature, cannot be pronounced destitute of value.

Certain activities, like the return of summer, and the occurrence of eclipses, proceed under the laws of matter which, to our cognizance, may be regarded as fixed and invariable. Others proceed in accordance with *methods*, or *laws*, made known to us through adequate observation and inference; and these furnish us grounds of anticipation scarcely less solid than the others.

We know, for instance, that if the earth continues its orbital and rotary motions without great change in the inclination of its axis; if the sun retains its efficiency, and all other conditions determining the present order of nature remain undisturbed, the seasons will continue to recur; evaporation and precipitation, freezing and thawing, will continue for a thousand or a million years to come, as they have continued through the past. If the principle of gravitation remains undisturbed, and the solvent and mechanical actions of moving water remain as now, it is certain that processes of aqueous erosion will continue to wear away the materials of the earth's crust; and the processes of sedimentation will continue to fill the undrained depressions of the earth's surface.

Thus, we may be satisfied that the Niagara gorge will be continued; and, if we use, as a rule, the slopes of the gorge already excavated, we may conclude that in the distant future, the bottom of the gorge will pierce the bottom of Lake Erie, and thus that lake will be gradually drained, and become a river. We may further reason that since lakes Huron and Michigan stand at nearly the same level as Lake Erie, these will be lowered as much as the latter; and because their depths exceed that of Lake Erie, there will result two or more small lakes, connected by a river, which will flow along the drained basin of Lake Erie, and down the steep, unnavigable slope, continuing through the Niagara gorge to Lake Ontario.

We may reason similarly about the general wear and wastage of the land. It has been estimated, from observation, that the surface of North America is lowered by denudation about one foot in four thousand years. This determination immediately suggests that the land is destined to undergo final wastage. As the detritus finds its way into the sea, the latter is slowly filling up, and the sea bottom will continually approach the level of the land. Unless the supply of surface water fails, the sea will eventually overflow the land. It may be supposed the tenor of past history argues for the future higher elevation of the land surfaces and deeper depression of the ocean's bottom. But we shall see that this anticipation is rendered nugatory by another one.

If the earth has been cooling from a highly heated condition, and still radiates more heat than it receives from the sun, we have ground for affirming, first, that the time will come, if it has not arrived, when the thermal energy contained within will be too feeble for the continued uplifting of continents and deepening of ocean basins; and thus the results of denudation will accumulate indefinitely.

If the earth still retains residual heat, from the era of primitive incandescence, then the cooled crust will continue to thicken, as this heat escapes into space. With the deepening of the cooled zone, additional water will be received in the pores of the earth. Calculations based on the absorbent capacity of average rocks show that the entire ocean is destined to be absorbed by the crust of the earth. It appears, even, that the capacity of the pores will be sufficient to receive the atmosphere also. The earth will hang in space without water or air. When the atmospheric envelope no longer exists, the sun's heat will no longer be blanketed in. The solar rays will be returned as rapidly as received, and the terrestrial surface will sink toward the temperature of external space.

The action of the moon on the lunar tidal protuberance is destroying the earth's rotary motion (page 299). A period may, therefore, be anticipated when the earth will turn constantly the same side toward the moon. If then the moon continues to revolve in the same period, each side of the earth will be exposed constantly two weeks to the scorching rays of the sun, to be turned during the next two weeks into the shadow, and exposed to the intense cold of planetary space.

But the moon will gradually recede from the earth, and will suffer a diminution of its tide-producing power, and of its power to impress the earth's rotation. If then the earth's distance from the sun remains about the same, the sun's action on the solar tide will tend to reduce the rotary motion of the earth to synchronism with its annual motion. One side of the earth will then be turned continually toward the sun, and the opposite side continually away from it. This train of contingencies might even be traced further; but that is here unnecessary.

The tendency of the diffusion of heat to a state of equilibrium threatens not alone the final refrigeration of the earth. The sun is inevitably approaching a state of final extinction. His light and heat will eventually become sensibly less; and in the distant æons of eternity the sun will become a dark, cold world.

Such eventualities might be traced still further. But it is not appropriate here to pursue reflections which verge so nearly on the domain of speculation. The purpose has been simply to illustrate the legitimacy and safety of reasoning from known principles to conclusions which lie even in the depths of the future eternity; and to show that the future conceals eventualities which must terminate the period of human existence on the earth. It is useful, also, to be reminded how small a speck of existence we are, and how brief an instant of duration is covered by a human lifetime, or the lifetime of a race. And assuredly, in the presence of such conceptions as those, we may feel a swelling admiration of that spiritual capacity in man which enables him to grasp and comprehend the events of periods past and to come which stretch out into the realm of eternity. It is a belief ingrained in the texture of the human soul, that a being whose thought thus rises superior to all time and space and change is destined, however brief his corporeal sojourn, to outlive in consciousness all the mutations compassed by the horizon of his thought.

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NOTE.—An asterisk (*) affixed to the number of a page indicates an illustration on that page, of the species or subject mentioned. A dagger (†) indicates a definition or explanation of a term; but it is used only where more than one reference exists.

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